9.4 PS&E DEVELOPMENT

This section prescribes procedures and policies for the preparation of PS&E's.

Plans are graphic representations (e.g., typical cross sections, drawings, details) of the proposed work.

Specifications are a general term applied to all directions, provisions and requirements concerning the quality and performance of the work for a project.

A cost estimate consists of the engineer's cost analysis to perform the work. It serves as the basis of the probable construction amount, to evaluate bidders' proposals and for programming funds for construction, related engineering, utility work, etc.

The *PS&E* package is a term used to describe the contract documents (i.e., plans, *Specifications*, estimate of cost) for performing the work to construct a highway facility. The following discussions will address those decisions generally made by the highway designer within the constraints imposed by earlier environmental and engineering studies.

9.4.1 Geometric Design

Geometric design defines the physical dimensions of the visible features of a highway (e.g., alignment, sight distance, width, slopes, grades, roadside treatment, related issues). Geometric design standards relate to the functional classification of highways, traffic density and character, design speed, capacity, safety, terrain and land use.

Design highways to a standard as consistent as practical. Evaluating the route between major terminal points will aid in keeping the overall design features of a route uniform on a project-by-project basis.

Limited funding may restrict the total reconstruction of a highway segment. When this is the case, the designer should consider *Stage Construction*. This is where the grading is completed first and the paving at a later time. This assures that the basic geometrics (i.e., alignment, grades, cross section) are acceptable without need of further modification.

9.4.1.1 Aesthetic Consideration in Highway Design

The visual aspect of the highway is one of the fundamental elements of any geometric design. Visual impacts encompass the view from and of the roadway. Curvilinear alignment fits the road to the terrain and provides a pleasing experience for the user.

The designer should be familiar with the design controls found in the *Green Book* in Chapter 3, *Combinations of Horizontal and Vertical Alignment-Alignment Coordination in Design*. These criteria are basic to good geometric design. Adhering to them will enhance the visual qualities of the roadway.

From an aesthetic standpoint, bridges should blend in with curvilinear alignment. Bridges should be located entirely on tangents, curves or transitions, but not on a combination of these. This may require minor adjustments in horizontal alignment (e.g., spiral lengths).

Design superelevation to avoid or minimize unsightly kinks, humps or dips in bridge railing or curbs.

Bridges placed on sag vertical curves can have problems with appearance and aesthetic value.

The ultimate test for an aesthetically pleasing facility is whether it truly enhances the area through which it passes. A good designer attempts to achieve this goal on all designs.

9.4.1.2 Horizontal and Vertical Alignment Relationship

Horizontal and vertical alignments are mutually related and what applies to one is generally applicable to the other. The designer should visualize the completed facility in a three-dimensional mode to ensure that the alignments complement each other and enhance the good features of both. Excellence in a coordinated design will increase the usefulness and safety of the highway, encourage uniform speed and make a positive contribution to the visual character of the road.

The *Green Book* covers the basic general guidelines for achieving coordination between line and grade. The following criterion applies:

- The curvature and grades should balance (i.e., flatter curves used with flatter grades, sharper curves with steeper grades).
- Tangent grade superimposed on tangent line and vertical curves on horizontal curves should be strived for at all times.
- Horizontal curves should lead vertical curves when they are superimposed so drivers can clearly see the direction the road is turning. The length of the vertical curve should preferably approach that of the horizontal curve.
- Sharp horizontal curves that are introduced at a pronounced crest or sag in the road grade may create hazardous driving conditions, especially at night.
- Both horizontal curvature and profile grade should be as flat as possible at intersections because sight distance along both roads is important and vehicles may have to slow down or stop.
- On two-lane roads, the need for safe passing sections often supersedes the desirability for a well-coordinated line and grade. In these cases, work toward a long tangent section or a very gentle curvature section having sufficient passing sight distance.

- The alignment should enhance scenic views, whether natural or manmade. The highway should head toward, rather than away from, those views that are outstanding. It should descend toward those features of interest at a low elevation, and it should ascend toward those features best seen from below or in silhouette against the sky.

9.4.1.3 Establish Control Points

The designer's approach to balancing horizontal and vertical alignment is essentially the same using aerial photographs, contour maps, quad sheets or other graphics showing the relief of the topography. The first step in coordinating both alignments is to establish the necessary physical control points that will set the parameters of the location. These control points can be either natural or manmade features (e.g., mountain passes, summits, bodies of water, developed areas, intersecting roadways, archaeological or historic properties, related constraints). In cases of reconstruction or RRR improvements, the existing roadside development and right-of-way limits may become primary control points.

The designer should plot a horizontal alignment through the established control points using splines, curve templates, shop curves or freehand methods. These preliminary layout stages avoid or limit the use of straightedges and string lines to evaluate a curvilinear design properly.

In rolling or mountainous terrain, it is desirable to plot a rough profile to determine if the preliminary alignment will fit the vertical controls. This consists of scaling stations on the horizontal alignment and picking elevations from the contours.

In rolling or mountainous terrain it is desirable to establish a series of horizontal controls that optimize the alignment's fit to the terrain. This is done by developing an initial profile that connects the elevations of the primary control points on a desired grade, then locating the profile grade interval elevations on the contour map in a series of uniformly spaced points at the calculated distance apart and coincident with the terrain contours.

A rough profile plot on a reduced scale ratio (e.g., 1:5000 (1:400) horizontal and 1:500 (1:50) vertical) is adequate to determine the need for alignment shifts. Several adjustments of the rough line and grade may be necessary before a reasonably good initial line complies with the geometric design requirements.

9.4.1.4 Horizontal Alignment

Horizontal alignment is a combination of circular curves, transition curves and tangents. Horizontal alignment must provide for safe and continuous operation at a uniform design speed for substantial lengths of highway.

The major design considerations in horizontal alignment are safety, functional classification, design speed, topography, vertical alignment, construction cost, cultural development and aesthetics. These factors, when properly balanced, produce an alignment that is safe, economical and in harmony with the natural contour of the land.

The following guidelines apply to all alignment projections:

- The line should be as directional as possible, consistent with topography and land use. A flowing line following the natural contours is preferable to one with long tangents slashing through the terrain and causing large construction scars.

- If possible, avoid the use of the minimum radius for the design speed. Where the minimum radius is required, design adjacent sections of the alignment to be curvilinear, with incremental decreases in radius, to minimize sudden reductions in operating speed.

- Consistent alignment is the desirable end product. Sharp curves introduced at the ends of long tangents and sudden changes from flat curvature to sharp curvature are dangerous. When sharp curvature is used, successively sharper transition curves from flat curvature to sharp curvature are applicable. This is necessary since actual operating speeds typically exceed design speeds on long flat curves (radius > 450 m (1,500 ft)) and tangents. The designer may assume 85th percentile operating speeds of 100 km/h (60 mph) approaching curves following tangents or flat curves longer than 500 m (1,600 ft).

- On long, high through-fills, use only very flat curvature unless guardrail or other measures (e.g., reflectors) are used to delineate the edge of the roadway.

- Small deflection angles should have long curves to avoid the appearance of a kink. Although undesired, deflections of 15 minutes and less do not require the use of a curve, but it is preferable to locate slight breaks in grade with vertical curves at these angle points to minimize the visible effect to the road user.

- Avoid abrupt reversals in alignment by providing enough room between curves for superelevation runoff or for spirals. See Section 9.4.1.4.2 for information on transition curves and Exhibit 9.4C for instructions on locating the flat section between reversing curves with short intervening tangents.

- Broken-back curves (adjacent curves in the same direction with short intervening tangents) violate drivers' expectations. Drivers expect a curve in the opposite direction of the one they just negotiated. When broken-back curves are visible for some distance ahead, they present an unpleasing appearance, even with tangents as long as 400 m (1,300 ft). It is desirable to introduce a reverse curve between them to eliminate the broken-back effect. In some cases, a single long curve or compound curve may replace the broken-back curve.

- Use compound curves cautiously because they can surprise the driver, and the change in radius is not easily recognized. They may be needed to eliminate excessive cuts or fills, encroachments into rivers or broken-back curves, but avoid their use on open highway alignment. A single curve with minimal additional impact is always preferable to a compound curve.

Because neither compound nor broken-back curves are desirable, it is up to the designer's experience and judgment to determine which to use in an unavoidable situation.

When designing for compounding curves, the radius of the flatter curve should not be more than one-and-a-half times that of the sharper curve. If this is impractical, design a partial spiral or a curve of intermediate radius between the main curves. The rate of change of a partial connecting spiral should be equal to or less than the average of the normal spirals used on the curves. Intermediate connecting curves should have a length not less than the runoff length for the flatter main curve as obtained from the superelevation runoff tables as shown in the *Green Book*.

The arc length of compound curves should be designed to provide at least five seconds of driving time on each curve.

A single design speed should normally apply for the full length of the compound curve. This requires different superelevation rates, which must be transitioned from one rate to the other over the full length of the partial spiral or the full length of the connecting curve. If neither a partial spiral nor intermediate curve is used, the superelevation transition should take place over a minimum length of 30 m (100 ft). Half the transition length should be on each curve.

After the alignment fits the controls of the highway location, reduce it to circular curves, transition spirals and/or connecting tangents.

9.4.1.4.1 Circular Curves

When CADD methods are used to establish the preliminary alignment, place a series of circular curves that best fit the primary control points, as well as the terrain horizontal controls described in Section 9.4.1.3. Check that the curves meet the guidelines for horizontal alignment projections described in Section 9.4.1.4, and connect the circular curves with tangent lines to form the preliminary alignment. Determine the superelevation runoff lengths and check that tangent lengths are sufficient to accommodate superelevation transitions. Determine the appropriate length of spiral curve transitions and add spiral transition curves between the circular curves and tangents when practical.

When splines or freehand methods are used to determine the preliminary alignment, the following procedure will approximate the radius of circular curve:

1. Select segments of the preliminary line that are uniform in curvature. Measure the long chord (C) and middle ordinate (M) of each alignment segment of uniform curvature.

2. Determine the radius (R) of the circular curve using Equation 9.4(1):

$$R = \frac{M}{2} + \frac{C^2}{8M} \qquad \text{Equation 9.4(1)}$$

3. Select the curve closest to the calculated value.

9.4.1.4.2 Transition (Spiral) Curves

A spiral transition curve allows for a gradual change in radius from infinity on the tangent to that of the circular curve so centrifugal force and side friction also develops gradually. The radius at any point on the spiral varies inversely with the distance measured along the spiral. In the case of a spiral transition connecting two circular curves having different radii, also referred as a partial spiral, there is an initial radius rather than an infinite value. Longer transition lengths can improve the aesthetic quality of the alignment. Spirals improve the appearance of a highway, reduce the lateral drift of vehicles entering and exiting curves, and simplify transitioning of superelevation and traveled way widening at the ends of curves. It is FLHO policy to encourage the use of spirals for smoother transitions and to enhance safety.

The minimum length of the spiral used to connect a circular curve to a tangent shall be the length required for superelevation runoff. A discussion on transition spirals is provided in the *Green Book* in Chapter 3*, Horizontal Alignment-Transition Design Controls*. The minimum superelevation runoff lengths are provided in Exhibit 3-32 in the *Green Book*. The desirable length of spiral curve transition is provided in Exhibit 3-37 in the *Green Book*. The designer should be aware that many States have adopted transition lengths greater than the minimum AASHTO requirements, therefore, State criteria applies in these cases. It should also be noted that some State DOTs prefer not to use spiral curves on their system.

9.4.1.4.3 Superelevation

The highway designer must consider design speed, maximum curvature and superelevation in horizontal alignment design. These design elements are related by the laws of mechanics and involve friction factors, centrifugal force, gravity, etc.

Design speed is based on the terrain, traffic and functional classification of the highway. Maximum superelevation considers the design speed and climatic conditions. Maximum curvature is a function of design speed and maximum superelevation. The *Green Book* in Chapter 3, *Horizontal Alignment-Design Considerations* provides guidance on selection of maximum superelevation rates. Where spirals are used, the superelevation runoff is applied uniformly over the full length of the spiral.

Superelevation is not necessary on flat curves because the centrifugal force developed by vehicles even at high speeds is minimal. Design these curves using a normal tangent crown section. See the *Green Book,* Chapter 3, *Horizontal Alignment-Design Superelevation Tables* for a discussion on the sharpest curve without superelevation.

On RRR projects, provide proper superelevation and transitions. When standard superelevation rates are impractical, the highest achievable rate applies, subject to approval through the design exception process. Even if it is not possible to construct the standard superelevation rate for a particular curve, is essential to design a consistent superelevation rate uniformly throughout the entire curve, with proper transitions. Where exceptions are necessary, engineering studies should identify locations for advisory speed and warning sign installations and other mitigation techniques.

In addition to improving superelevation, consider flattening curves when crash data indicates that geometrics are a contributing factor.

Within the constraints imposed by adjacent development (e.g., curbs, sidewalks, arterial streets), urban highways should be superelevated the same as rural highways.

9.4.1.4.4 Transition Sections

Tangent sections of roadways carry normal crown. Curved sections are superelevated. Transitions make a gradual change from one to the other. Superelevation runoff is the length of roadway used to transition from full superelevation on a curve to a flat section on the outside lane on the adjoining tangent. Tangent runoff is the length of tangent required to transition from the above flat section to full crown. Under normal conditions, the distance is prescribed by the rate of superelevation. A detailed discussion of runoff is in the *Green Book* in Chapter 3, *Horizontal Alignment-Transition Design Controls*.

Where the alignment consists of tangents connected by circular curves, typically, the superelevation begins on the tangent, and full superelevation is attained some distance into the curve.

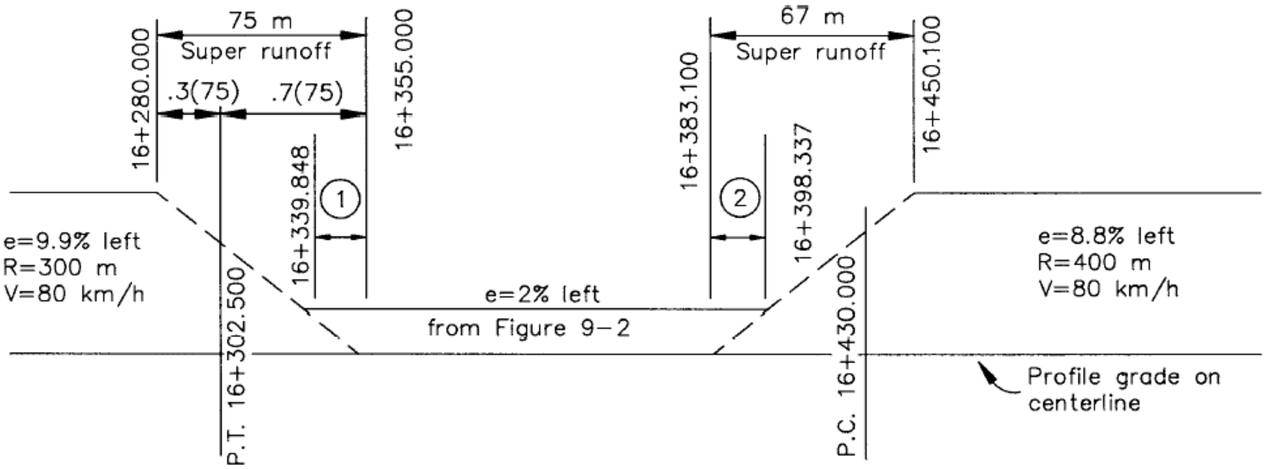
Design practice is to place about two-thirds of the runoff on the tangent approach and one-third on the curve. With a short tangent distance between reversing curves, the runoff length may require up to one-half of the length on the curve and one-half on the tangent. With a short curve length, the runoff length may be as little as 20 percent of the length on the curve and 80 percent on the tangent.

Give special attention to superelevation transition for broken-back curves. Exhibits 9.4-A and 9.4-B give guidance in providing an adequate transition between curves in a broken-back situation.

Exhibit 9.4-C shows a method of checking templates for flat sections between reversing curves with a short tangent.

Many vehicles operate at speeds higher than the design speed on long tangents and flatter curves. These vehicles have to slow to the design speed in order to safely and comfortably negotiate the sharpest curves. In areas of sharp curves, the radius and the superelevation of adjacent curves should be designed to limit the difference in operating speed between the curves to a maximum of 20 km/h (15 mph), and preferably to less than 10 km/h (5 mph). If the maximum differential is exceeded, the plans must include advance curve and advisory speed signs for the lower speed curves. Additional delineation of the lower speed curvature should be considered on a case-by-case basis (e.g., delineators, raised pavement markers, chevrons).

The Interactive Highway Safety Design Model (IHSDM) provides methodology to determine the predicted operating speeds for a particular design and horizontal alignment.



Example:

Tangent distance P.T. to P.C. 16+430.000-16+302.500=127.500 m (425.000 ft)
Transition super rate from Exhibit 9.4-B for 80 km/h (50 mph) and 127.500 m (425.000 ft) tangent=2%

① 020(75)=15.152 m .099	(Metric)
① .020(250)=5.00 ft	(US Customary)

Imaginary curve station = 16+355.00 – 15.152 = 16+339.848 (Metric)
= 16+355.10 – 5.000 = 16+350.000 (US Customary)

② .020(67)=15.227 m .088	(Metric)
② .020(225)= 4.500 ft	(US Customary)

Imaginary curve station = 16+383.100 + 15.227 = 16+398.337 (Metric)
= 16+383.000 + 4.500 = 16+387.500 (US Customary)

Exhibit 9.4-A SUPERELEVATION TRANSITION ON SHORT TANGENTS BETWEEN BROKEN-BACK CURVES

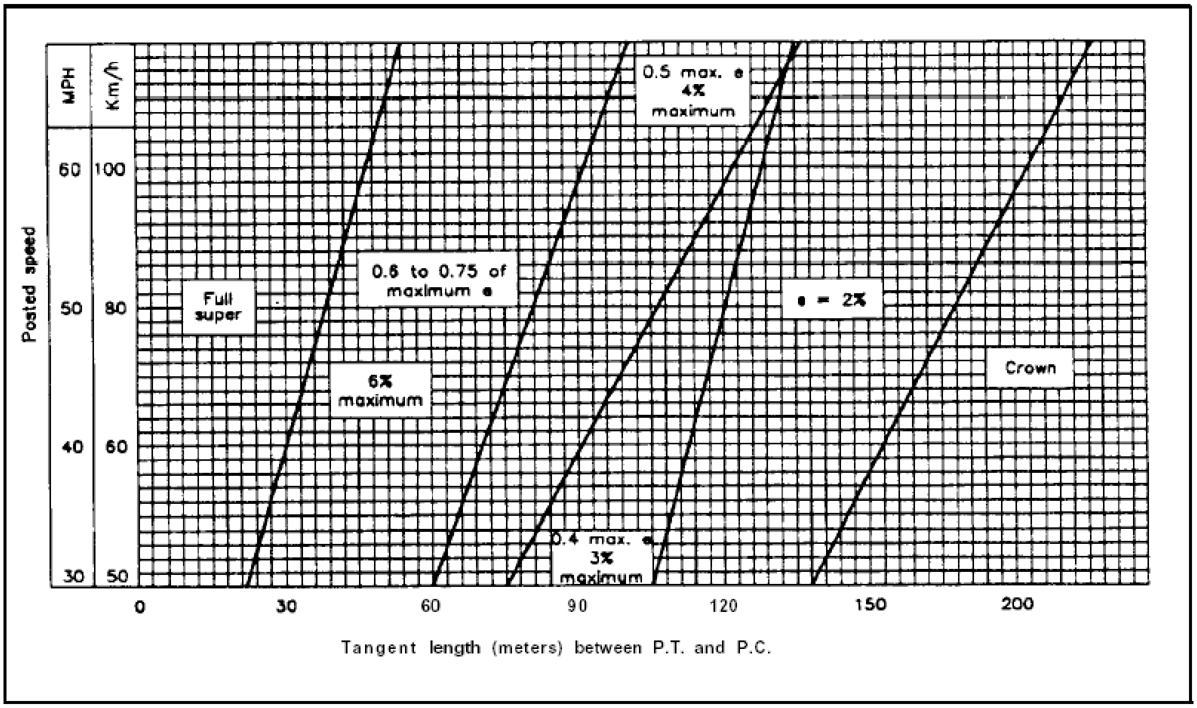
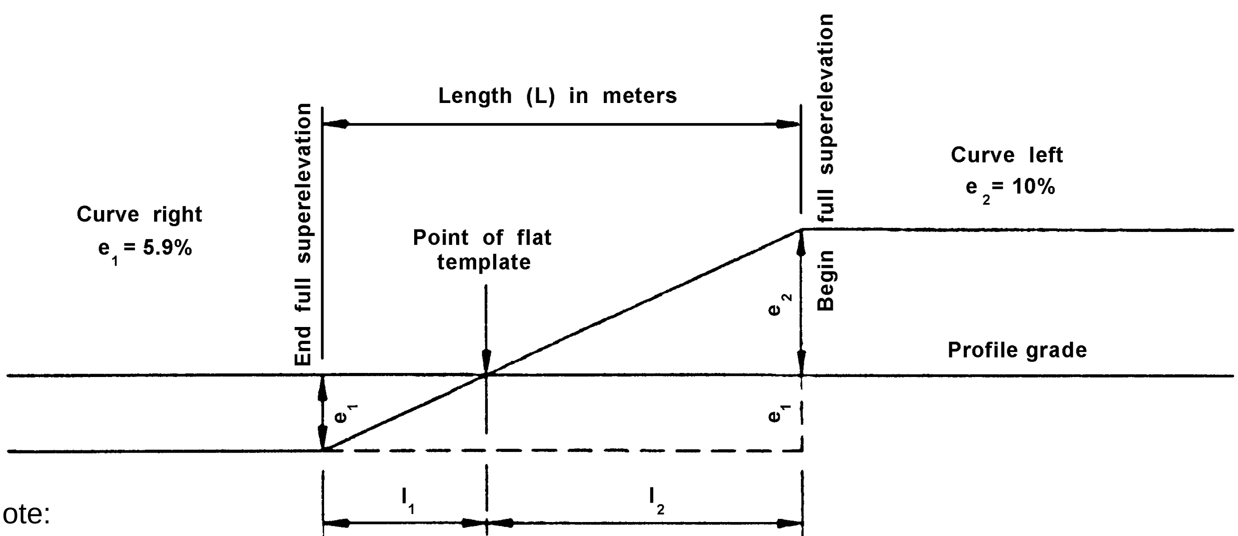


Exhibit 9.4-B SUPERELEVATION TRANSITIONS FOR BROKEN-BACK CURVES



Note:

Ratio $\frac{l_1}{L} = \frac{e_1}{e_1+e_2}$ or $\frac{l_2}{L} = \frac{e_2}{e_1+e_2}$

Therefore $l_1 = \frac{(e_1)(L)}{(e_1+e_2)}$ or $l_2 = \frac{(e_2)(L)}{(e_1+e_2)}$

Exhibit 9.4-C DETERMINING FLAT SECTIONS BETWEEN REVERSING CURVES WITH SHORT TANGENTS

If design speed for a horizontal alignment is increased, all design criteria must meet the standards for the increased speed. Where there is not enough runoff length between curves, redesign them to provide the runoff length, or address the situation as a design exception.

9.4.1.5 Vertical Alignment

Vertical alignment consists of a series of gradients connected by vertical curves. Applicable design controls include safety, topography, functional classification, design speed, horizontal alignment, construction cost, cultural development, drainage, vehicular characteristics and aesthetics. The terms vertical alignment, profile grade and grade line are interchangeable.

The topography of the land has an influence on alignment. AASHTO separates topography into three classifications of terrain:

- level or flat,
- rolling, and
- mountainous.

A description of these three types of terrain is in the *Green Book* in Chapter 3*, Vertical Alignment-Terrain*.

Terrain classifications pertain to the general character of a specific route corridor. For example, routes in mountain valleys and mountain passes that have all the characteristics of level or rolling terrain should be classified as such. The terrain classification determines the maximum allowable grades in relation to design speed.

9.4.1.5.1 Vertical Alignment (Grade)

Once the horizontal line is in the CADD system, the designer should obtain a plot of the ground line and establish the vertical control points. Project the profile grade to fit these control points and the standards for percent of grade and vertical curve length. To produce a desirable vertical alignment, the designer should use the following guidelines:

- Use a smooth grade line with gradual changes, consistent with the type of highway and character of terrain. Avoid numerous breaks and short grade lengths.

- Avoid hidden dips. Hidden dips are hazardous on two-lane highways. They can hide approaching or slow moving vehicles or obstructions on the road ahead while deceiving the driver into believing that it is safe to pass or travel at high speed. Use long straight grades or introduce horizontal curves in conjunction with vertical curves to break up unsafe long tangents.

- Long steep grades affect traffic operation. If traffic volume is high, a slow moving vehicle lane or turnout requires study. On long downgrades, consider a truck escape ramp.

On some steep grades, especially on low-speed roads, it may be desirable to break a sustained grade by making it steeper at the bottom and flatter at the top. Short intervals of flatter grade permit high-powered vehicles to accelerate and pass underpowered vehicles.

- On switch-back curves, flatten the grade to facilitate speed reduction and vehicle operation at slower speeds.
- Avoid broken-back grade lines. Two vertical curves in the same direction separated by short tangents is poor design practice particularly in sags where both curves are visible at the same time.
- Sag vertical curves at the ends of long tangents should be several times the length required for stopping sight distance to avoid the appearance of an abrupt change in grade.
- When at-grade intersections occur on roadways with moderate to steep grades, it is desirable to reduce the grade through the intersection.
- In swampy terrain and areas subject to overflow and irrigation, the low point of the subgrade should be at least 0.5 m (1.7 ft) above the expected high water. For roads located along main streams and rivers, refer to Chapter 7 for the appropriate hydraulic controls.

9.4.1.5.2 Maximum Grade

The designer should know the functional classification of the project from the planning and programming process (see Chapter Two). Consider this data, information provided in the *Green Book* in Chapter 3, *Vertical Alignment-Grades* and the type of topography to determine the maximum allowable grades in relation to design speed.

Example 9.4-1:

Given:

Rural Area
Highway Functional Classification is Rural Collector
60 km/h (40 mph) Design Speed
Rolling Terrain

According to the *Green Book* (Exhibit 6-4, Maximum Grades for Rural Collectors), the maximum grade for this example is eight percent.

When analyzing maximum grades, note that superelevation transitions will increase the effective grade on the edge of the traveled way. This increase is significant, particularly to trucks and recreational vehicles. To minimize this effect on long continuous runs of near maximum grades, the designer should flatten the grade throughout the horizontal curve.

Consideration of the effect of superelevation transition on the maximum grade at the edge of roadway is especially important when the design contains climbing lanes or scenic pulloffs.

9.4.1.5.3 Minimum Grade

Flat and level grades on uncurbed pavements are not objectionable when the pavement is adequately crowned to drain the surface laterally.

A flat grade (zero percent) is acceptable along through-fill sections where the highway has sufficient crown. Minimum grades (one-half percent minimum, one percent desired) are applicable only for drainage of roadway ditches in cut sections, drainage of curb sections and to ensure pavement drainage on superelevation transitions. This requirement particularly applies where flat grades on crest and sag verticals have substantial lengths that are essentially flat. It also applies where superelevation transitions introduce sags in the ditch or gutter line. Computer plots of the ditch or gutter profiles will highlight any drainage problems for correction as the design progresses.

See Section 9.4.1.7 for details on design of drainage.

9.4.1.5.4 Vertical Curves

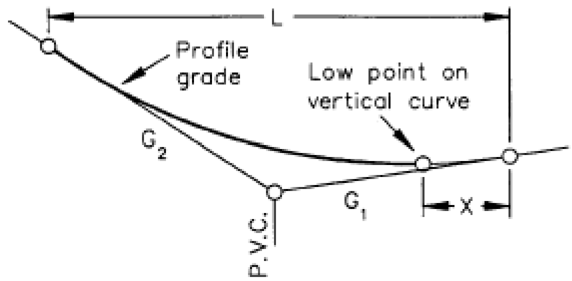
Vertical curves provide a gradual change between tangent grades. (See Exhibit 3-69, Types of Vertical Curves in the *Green Book*.) For simplicity, the symmetrical parabolic curve with an equivalent vertical axis centered on the vertical point of intersection (VPI) is common in roadway profile design. On certain occasions, critical clearance or other controls require the use of unsymmetrical vertical curves.

Exhibit 9.4-D provides a method of determining the low point on a vertical curve when the grades are unequal. This will identify locations for the installation of pipe culverts, catch basins or other such drainage facilities.

Exhibit 9.4-E shows a way to eliminate a series of broken-back curves.

9.4.1.5.5 Critical Lengths of Grade

Maximum grade, in itself, is not a complete design control. The length of a particular grade in relation to desirable vehicle operation requires analysis. The critical length of grade is the maximum length of a designated upgrade on which a loaded truck can operate without an unreasonable reduction in speed. Studies show that regardless of the average speed on the highway, the greater a vehicle deviates from this average speed, the greater its chances of becoming involved in a crash. A 15 km/h (10 mph) reduction in truck speed determines critical



Where:

G_2 = Steeper grade (%)

G_1 = Flatter grade (%)

L = Length of vertical curve (m(ft))

$X = \dfrac{G_1(L)}{G_2+G_1}$ Distance in (m(ft)) from end of vertical curve of flatter grade to low on vertical curve.

Example:

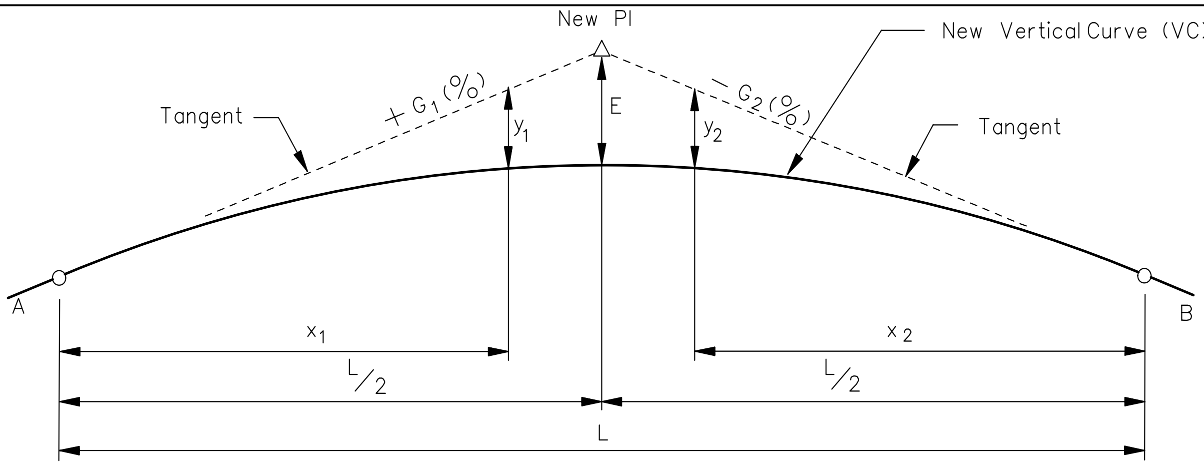
Let G_2 = 4% and G_1 = 2%

L = 300 m (1,000 ft)

therefore $X = \dfrac{(+2)\,(300)}{4+2} = \dfrac{600}{6} = 100$ m (Metric)

therefore $X = \dfrac{(+2)\,(1{,}000)}{4+2} = \dfrac{2{,}000}{6} = 333$ ft (US Customary)

Exhibit 9.4-D DETERMINING LOW POINTS ON VERTICAL CURVES WITH UNEQUAL GRADES



VC = vertical curve

To determine the station and elevation of a new PI by extending existing grades to intersection:

1. Select a random even station for point A and determine the elevation for it from the old grade PI. Elevation of Point B = Elevation of Point A.

2. Determine the station of Point B from the old grade PI.

3. Distance L equals difference in stations between A and B in meters (feet):

G_1 = Ascending grade (%)
G_2 = Descending grade (%)

$$x = \frac{G_2 L}{G_1 + G_2}$$

$$y = L - x$$

$$\text{Elevation of new PI} = \text{Elevation point A} + \frac{G_1 X}{100}$$

$$= \text{Elevation point B} + \frac{G_2 Y}{100}$$

Note: For small changes in grade (A) or for small values of (K), the computed lengths of vertical curves may be very short. For these conditions, use the minimum lengths specified in Exhibit 9.4I instead of the calculated length, provided it is longer. When practical, it is desirable to design vertical curves of 150 m (500 ft) or more in length, in order to create a pleasing appearance.

Exhibit 9.4-E ELIMINATING BROKEN-BACK VERTICAL CURVES

lengths of grade. The *Green Book* has a discussion on this subject and recommendations for different conditions in Chapter 3, *Vertical Alignment-Grades*.

9.4.1.6 Sight Distance

Sight distance is the continuous length of roadway ahead that is visible to the driver. Of prime importance is the arrangement of geometric elements so that adequate sight distance exists for safe and efficient operation.

The sight distance available on horizontal curves depends on the radius of the curve and the location of obstacles to the line of sight across the inside of the curves. Obstacles (e.g., cut slopes, tall grass on cut slopes, trees, shrubs, farm crops, buildings, bridge abutments and walls, bridge railing, guardrail) may limit the sight distance. To provide for safe operation, horizontal sight distance must equal or exceed the safe stopping distance for the selected design speed. These distances are listed on Exhibit 3-1, Stopping Sight Distance in the *Green Book*. To obtain the required sight distance, the designer may flatten curves or provide for the removal or relocation of obstacles.

Crest vertical curves may also limit the horizontal sight distance, especially in cut sections. The designer must take this into consideration when crest vertical curves coincide with horizontal curves and there is a substantial change in grade. This case may require a longer vertical curve, flatter horizontal curve, wider and deeper ditch, additional clear area beyond the ditch or shoulder, or a combination of these.

Four sight distances are considered in design:

- Stopping Sight Distance (SSD),
- Decision Sight Distance (DSD),
- Passing Sight Distance (PSD), and
- Intersection Sight Distance (ISD).

Sight distances directly relate to the design speed of the road.

Intersection sight distances for at-grade intersections, including railroad crossings and private road approaches, are a separate topic covered in Section 9.4.2.

9.4.1.6.1 Stopping Sight Distance

A roadway design requires minimum stopping sight distance at all points, and where economically justified more liberal stopping distances are desirable.

Minimum stopping distance is the least distance required to bring a vehicle to a stop under prevailing vehicle and climatic conditions. It depends on the initial speed of the vehicle, the perception and reaction time of the driver, and the coefficient of friction between tires and roadway for the prevailing conditions. The coefficient of friction is much lower for wet pavements; therefore, wet rather than dry pavement conditions apply for establishing minimum values.

Design controls for SSD are in the *Green Book* in Chapter 3 under *Sight Distance-Stopping Sight Distance*, *Horizontal Alignment-Sight Distance on Horizontal Curves*, *Vertical Alignment-Crest Vertical Curves* and *Vertical Alignment-Sag Vertical Curves*.

9.4.1.6.2 Decision Sight Distance

Decision sight distance is the length of road a driver needs to receive and interpret information, select an appropriate speed and path and begin and complete an action in a safe maneuver. This distance is greater than the distance needed to simply bring a vehicle to a stop, and provides for a reasonable continuity of traffic flow.

If possible, provide decision sight distance in advance of any feature requiring increased driver awareness and action. This includes intersections, lane changes, congested areas, pedestrian crossings or other features. When decision sight distance is unavailable and relocation of the feature is not possible, the designer shall provide suitable traffic control devices.

See design controls for DSD in the *Green Book* in Chapter 3, *Sight Distance-Decision Sight Distance*.

9.4.1.6.3 Passing Sight Distance

Passing sight distance is generally applicable only to two-lane, two-way roads. It is important for reasons of safety and service to provide as many passing opportunities as possible in each section of road. The designer should try to ensure there are no long sections where passing is not possible. The available passing sight distance has considerable influence on the average speed of traffic, particularly when a road is operating near capacity.

The economic effects of reduced speed are indeterminate, but there is no doubt that road users benefit considerably when operating at or near design speeds with minimal traffic interference. The designer should consider these economic effects when setting horizontal and vertical alignments.

Passing sight distance seldom applies on multilane roads. However, passing sight distance at the end of truck-climbing and passing lanes where traffic must merge requires consideration.

The designer should strive to increase the sight distance in areas adjacent to passing zones where vehicles may operate above the design speed.

Standard minimum passing distances for all classes of two-lane roads are given in the *Green Book*, Exhibit 3-7, Passing Sight Distance for Design of Two-Lane Highways. Also, refer to guidance in the *Green Book* in Chapter 3, *Sight Distance-Passing Sight Distance for Two Lane Highways*.

Design minimum passing sight distance requirements should not be confused with values provided in the *MUTCD* for determining no-passing zone pavement striping.

9.4.1.6.4 Restrictions

Sight distance on horizontal curves is proportional to the radius of the curve. Manmade objects or naturally occurring conditions can restrict the line of sight across the inside of a curve. Typically, vegetation or a cut slope restricts sight distance.

Provide adequate sight distance on horizontal curves by selecting the proper curve radius and arranging for the removal or relocation of obstacles. See Exhibit 9.4-F for an example of a sight line offset (M) on a cut slope.

Stopping sight distance (SSD) for the design speed of the highway must be provided on all horizontal curves as a minimum. The SSD is measured from the eye height of a passenger car driver, 1080 mm (3.5 ft) above the center of the inside lane, to an object 600 mm (2.0 ft) high on the center of the inside lane on the highway ahead.

The designer must provide at least the minimum SSD for every portion of the highway. When the minimum SSD is not possible to provide, address the situation as a design exception.

The minimum lengths of vertical curves used in design are determined by Equation 9.4(2):

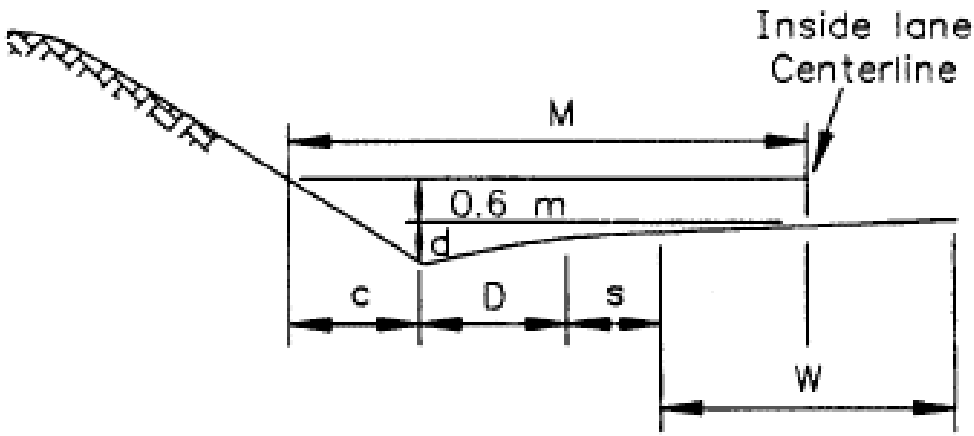
$$L = AK \qquad \text{Equation 9.4(2)}$$

Where:

L = Minimum length of vertical curves in m (ft). (Round up to even tens, fifties or hundreds.)

A = Algebraic difference in grade (percent).

K = Rate of change of grade (a constant value for a particular design speed and type of sight distance).



Offset (M) = c + D + s + 0.5W

Where:

c = the drop (d) from the center of the inside lane to the bottom of the ditch plus 0.6 m (2.0 ft) multiplied by the cut slope ratio.

D = the total ditch width from bottom of ditch to edge of shoulder.

s = the shoulder width

W = width of the inside lane

Note: When vegetation is expected to grow on the cut slope, the drop (d) should be reduced by the estimated depth of the vegetation. On crest vertical curves, (d) should be reduced appropriately. On sag vertical curves, (d) should be increased.

When vegetation is not controlled on the cut slope, reduce c to zero.

Exhibit 9.4-F LATERAL CLEARANCE FOR STOPPING SIGHT DISTANCE

9.4.1.7 Geometric Cross Section

The highway cross section is defined as the finished or the proposed finished section between construction limits. (See Exhibit 9.4-G.)

Roadway section configurations depend on functional classification criteria. The criteria show the cross-section characteristics of the roadway section based on the *Green Book*, State developed and approved classifications, *NPS Standards* or other applicable agency standards.

Most Federal roads have an asphalt concrete surface. Some highways are graded under several contracts and the ultimate pavement is placed where a long section of the route is ready. Under the grading contracts, the base courses may be placed and then surfaced with an interim asphalt surface treatment. Occasionally, a roadway with gravel surfacing is requested by the client agency.

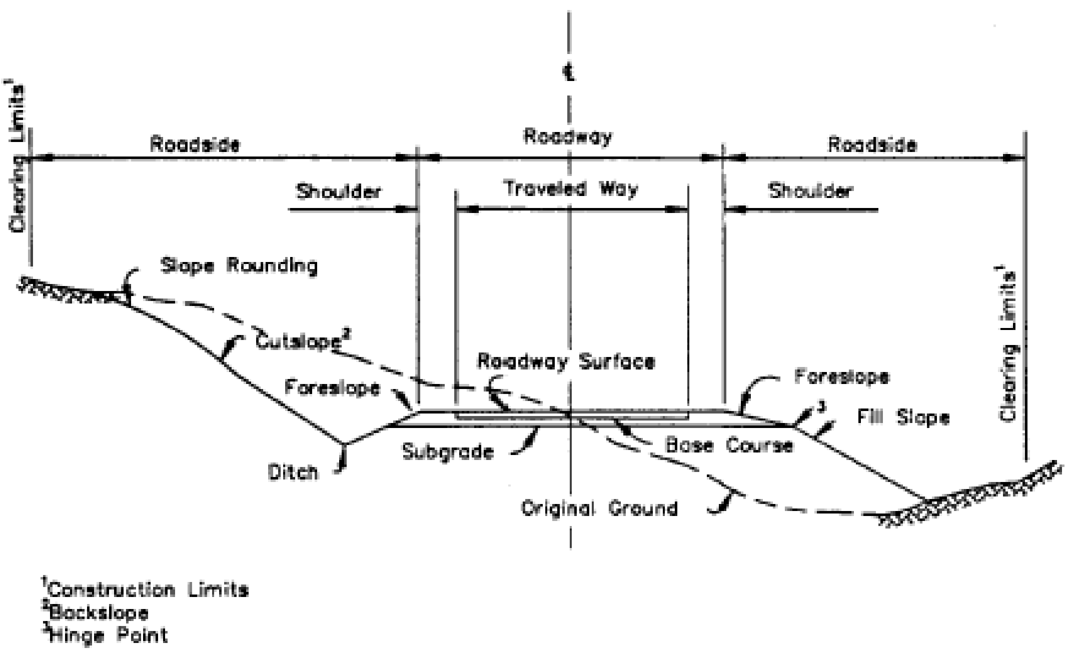


Exhibit 9.4-G TYPICAL ROAD CROSS SECTION ELEMENTS

9.4.1.7.1 Pavement Structure

The pavement structure refers to the material and depth of base and pavement placed on the finished subgrade. The pavement structure design should use the minimum depth of material necessary to carry the projected loads over the design life of the pavement. The design shall also provide for a smooth-riding, skid-resistant surface.

A normal pavement structure design has a 10- to 20-year life. The geotechnical staff bases the design on soil samples and the predicted volume and type of traffic using the highway during the design life. The pavement structure thickness varies with climatic conditions and the type and strength of subgrade material used (usually in the top 300 mm to 600 mm (1 ft to 2 ft) of subgrade).

Generally, free-draining, high-strength materials require less thickness than low-strength materials containing clay or silt. See Chapter 6 for the design of structural overlays including minimum thicknesses.

At the beginning of a design, the depth of the pavement structure may be arrived at by an assumption based on experience or by comparing with the depths used on an adjacent project. Following a geotechnical investigation, the designer will adjust the assumed depth accordingly. The geotechnical investigation usually takes place after a line and grade have been established.

For RRR projects, the riding quality of an asphalt surface may be improved by providing a leveling course. This additional depth may increase the pavement structure capabilities and merits consideration in the final pavement design when leveling is relatively uniform over the length of the project. If a field review of the project is not practical, the designer should increase asphalt concrete pavement quantities by 20 percent for use as leveling material. See Chapter 6 for additional details on the design of asphalt and concrete pavements.

9.4.1.7.2 Profile Grade Location and Cross Slope

The standard location of profile grade on the highway cross section is at centerline or low-side of the superelevated section for all two-lane highways.

The cross slope on tangents on paved highways must be from one-and-a-half to two percent.

Normally, the cross slopes on gravel surfaced roads must be three to four percent.

The shoulder cross slope should be the same as the adjacent traffic lane. With curb sections or when the shoulder surface is an asphalt surface treatment, aggregate or turf, increasing the slope helps to facilitate drainage. In these cases, consider cross slopes of four to six percent. On super elevated curves, the roll-over in cross slope on the outside of the curve should not exceed eight percent.

The cross slope on the tops of base courses and the subgrade is usually the same as on the finished pavement. In some cases it is desirable to have a reverse slope on the subgrade (on the high side of curves and outside the edge of the pavement) to prevent moisture from entering the base.

9.4.1.7.3 Lane and Shoulder Widths

The *Green Book* and other agency standards show lane and shoulder widths for each functional classification for various design speeds and traffic volume ranges.

When the percentage of trucks or recreational vehicles is high in comparison to the ADT, consider increasing lane widths.

9.4.1.7.4 Foreslopes

Foreslopes ensure the stability of the roadway and provide an opportunity for recovery of an out-of-control vehicle. The foreslope, the slope from the edge of the surfaced shoulder to the edge of the subgrade shoulder, should be in accordance with the AASHTO's *Roadside Design Guide*.

The slope from the edge of the subgrade shoulder to the bottom of the ditch should normally be an extension of the foreslope.

On RRR projects, the proposed work on the roadway will typically affect the foreslopes from the edge of pavement to the hinge point of the fill slope and ditch foreslopes.

The following points should also be noted:

- Foreslopes steeper than 1V:4H are traversable but are not considered recoverable and should be avoided.

- When the existing roadway geometrics are retained and the foreslopes are steeper than 1V:4H, reshaping to provide a flatter foreslope is desirable.

- There are cases where the roadbed width will not accommodate foreslopes of 1V:4H or flatter. There also may be restrictions on the filling of ditches to provide width or widening of embankments. When this occurs, consider strengthening the existing pavement structure through a recycling-in-place process rather than overlaying the project. A narrower pavement width to maintain a 1V:4H foreslope and prevent an undesirable edge drop-off may be a reasonable solution.

- It is desirable to flatten crossroad/road approach foreslopes to 1V:10H. Provide at least a 1V:4H minimum slope. Move the crossroad/road approach drainage away from the mainline to maintain the integrity of the clear zone and reduce the length of pipe required.

9.4.1.7.5 Roadway Ditches

The ditch cross section must be adequate to accommodate drainage of the pavement and cutslope. Chapter 7 covers the details of hydraulic design.

Ditches should have a streamlined cross section for safety (see *Roadside Design Guide*) and ease of maintenance. Wide ditch bottoms are used in rock fallout areas as well as in projects designed with side borrow.

Roadway ditches commonly have a "V" shape formed by the foreslope from the subgrade shoulder and cut slope. The depth of the ditch is dependent on hydraulic needs. It should normally be from 150 mm to 300 mm (6 in to 1ft) below subgrade for drainage and maintenance purposes. When hydraulic needs dictate ditches of greater capacity, a flat bottom ditch takes precedence over deepening the v-ditch. Flat bottom ditches perform better than "V" ditches from a hydraulic and safety standpoint, but are less simple to construct.

The designer should obtain computer plots of the roadway ditch profiles to check for sags in the ditch line. These profiles will show where the installation of culverts or the construction of special ditch grades will eliminate ponding.

At the ends of cuts, it is normal to widen ditches for rounding purposes as shown in Exhibit 9.4-H. Using the special ditch grade criteria files in CADD will accomplish this objective.

9.4.1.7.6 Cut and Fill Slopes

The design of cut and fill slopes is a compromise between aesthetics, safety, stability, and economics. Generally, low cuts and fills are economical to construct on relatively flat slopes and will enhance aesthetics, safety, and maintenance. Slopes 1V:3H are generally traversable by a vehicle that has run off the road but do not provide for vehicle recovery. Slopes 1V:3H and flatter are also traversable by self-propelled mowers, and should be used at locations where the grass will be regularly cut. High cuts and fills normally have steeper slopes.

Cuts have a high visual impact, therefore, the design of cut slopes requires careful consideration. In some cases, it is desirable to use the same slope throughout the cut, while in other situations a constant distance to the catch point stake and a continuously varying slope may be appropriate.

In steep terrain, the slopes may be varied slightly from standard slopes in order to better fit the topography or eliminate high "sliver" cuts or fills. Transition slopes between common material and rock require special consideration. Blend the ends of cut slopes into the natural terrain by rounding, flattening, or otherwise shaping the ground line.

Transition fill slopes from the main portion of the fill into the cut section. Transitions between flat and steep slopes should be sufficiently long to provide a pleasing appearance. A transition from a 1V:4H slope to a 1V:1.5H slope may require a distance of 50 m (164 ft) or more to appear natural.

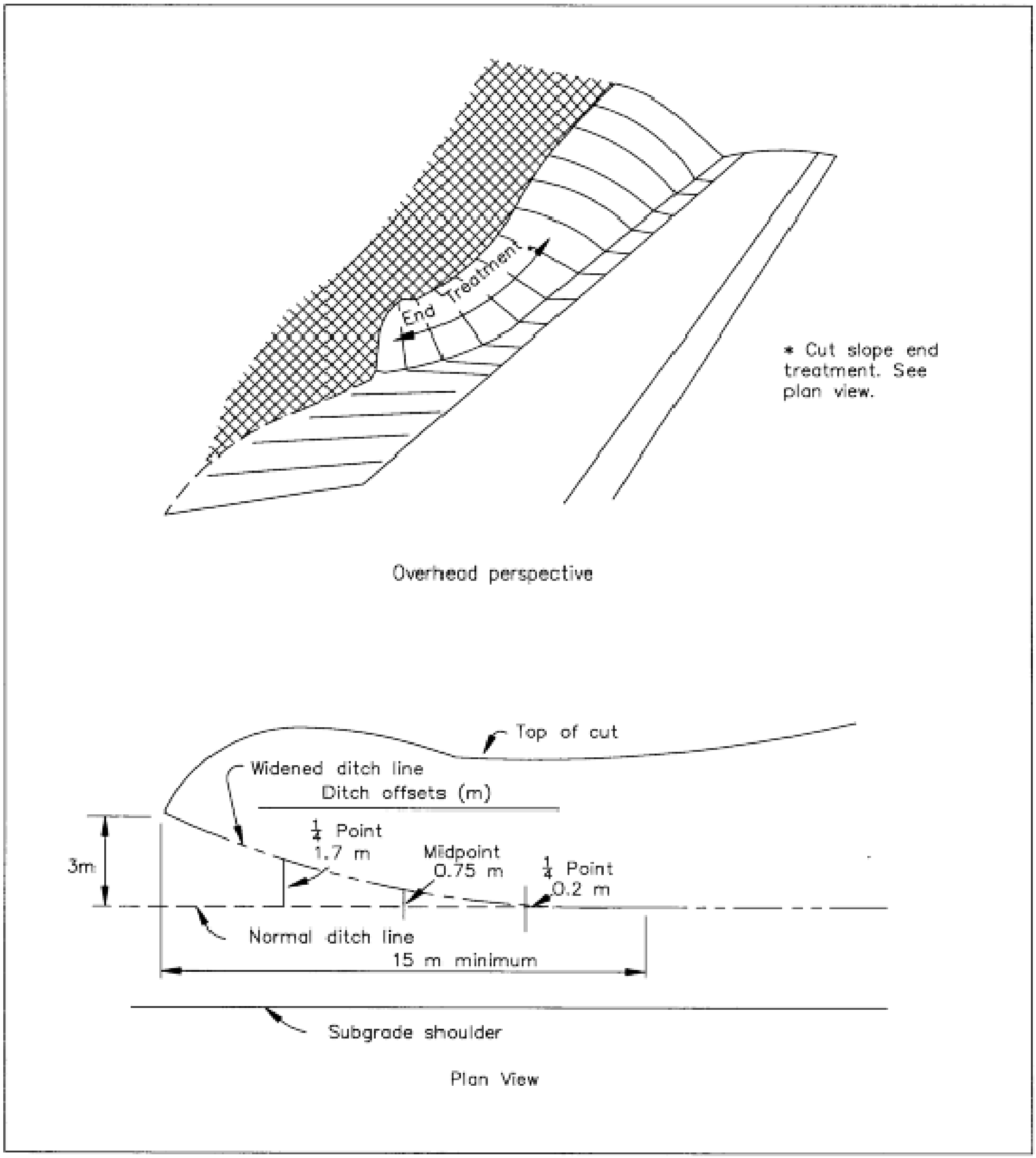


Exhibit 9.4-H TYPICAL CUT SLOPE END TREATMENT

Exhibit 9.4-I lists commonly used slopes for cuts and fills in earth materials. Use this table as a guide, along with the recommended slopes in the geotechnical report, to design the slopes on the project. All fill slopes steeper than 1V:4H should be evaluated for safety. See the *Roadside Design Guide* and Chapter Eight for additional guidelines.

Geotechnical reports may not be available for the project when beginning a design. If this is the case, design cut and fills slopes based on available survey or field review data. When a geotechnical report becomes available, the designer must review the slopes initially used and make any necessary adjustments in the earthwork design.

9.4.1.7.7 Rock Cut Slopes

Generally, rock slopes vary from near vertical to 2V:1H, depending on the type and quality of rock, joint patterns, fractures, cross bedding, etc. Rock slopes dipping toward the roadway may require flatter slopes.

High cuts, particularly in weathered or weak rock, may require fallout ditches for stability and safety. A fallout ditch at the bottom of high rock cuts keeps falling rock from encroaching on the highway. A geotechnical investigation will determine the need for fallout ditches, their width and necessary configuration.

Cut and Fill Slope Ratios for Soil Materials

Height		Slope Type	Flat		Rolling		Mountainous	
(m)	(ft)		Des.	Max.	Des.	Max.	Des.	Max.
0-1	0-3.3	Cut Fill	1V:6H 1V:6H	1V:4H 1V:4H	1V:6H 1V:6H	1V:4H 1V:4H	1V:6H 1V:6H	1V:3H 1V:4H
0-3	3.3-10	Cut Fill	1V:4H 1V:4H	1V:3H 1V:4H	1V:3H 1V:4H	1V:2H 1V:4H	1V:3H 1V:3H	1V:2H 1V:3H
3-4.5	10-15	Cut Fill	1V:3H 1V:4H	1V:2H 1V:3H	1V:3H 1V:4H	1V:2H 1V:3H	1V:3H 1V:3H	1V:2H 1V:1.5H
4.5-6	15-20	Cut Fill	1V:3H 1V:3H	1V:2H 1V:2H	1V:2H 1V:3H	1V:2H 1V:2H	1V:2H 1V:2H	1V:1.5H 1V:1.5H
Over 6	Over 20	Cut Fill	1V:2H 1V:3H	1V:1.5H 1V:2H	1V:2H 1V:3H	1V:1.5H 1V:1.5H	1V:2H 1V:2H	1V:1.5H 1V:1.5H

Note: Cut and fill slopes steeper than 1V:2H should be avoided in clay or silty soils subject to erosion. Fill slopes steeper than 1V:1.5H may be used in critically tight areas with geotechnical guidance when the fill material is composed of quality rock.

Exhibit 9.4-I DESIRABLE AND MAXIMUM SLOPES

When soil or highly weathered rock overlays the solid rock, overburden benches at the top of the solid rock may be desirable. The overburden slope should range from 1.33V:1H to 1V:2H, depending on the type and depth of overburden and the steepness of the topography. When the rock surface is known, compound slopes work very well.

From a safety viewpoint, rock cuts should be vertical or nearly vertical if the rock will stand on these slopes. Under these conditions, falling rocks seldom roll once they hit the ditch. Rock cuts on the inside of curves designed on 5V:1H or flatter slopes prevent the appearance of an overhang to drivers.

Exhibits 9.4-J and 9.4-K provide guidance for designing rock cuts and fallout ditches. However, the final design shall rely on the recommendations in the geotechnical report. Typical sections for rock cuts should be shown on the plans.

The normal rockfall protection is provided by the typical V-ditch with the minimum width shown in Exhibit 9.4-J. Rock slopes higher than 10 m (30 ft) from shoulder grade may require wider fallout ditches and the geotechnical staff should be consulted. Cuts less than 6 m (20 ft) in height generally do not require a fallout ditch.

The added rock protection features shown in Exhibits 9.4-J and 9.4-K may be applicable on higher volume highways experiencing falling rock. The Geotechnical Unit should recommend or approve these features before inclusion into a project.

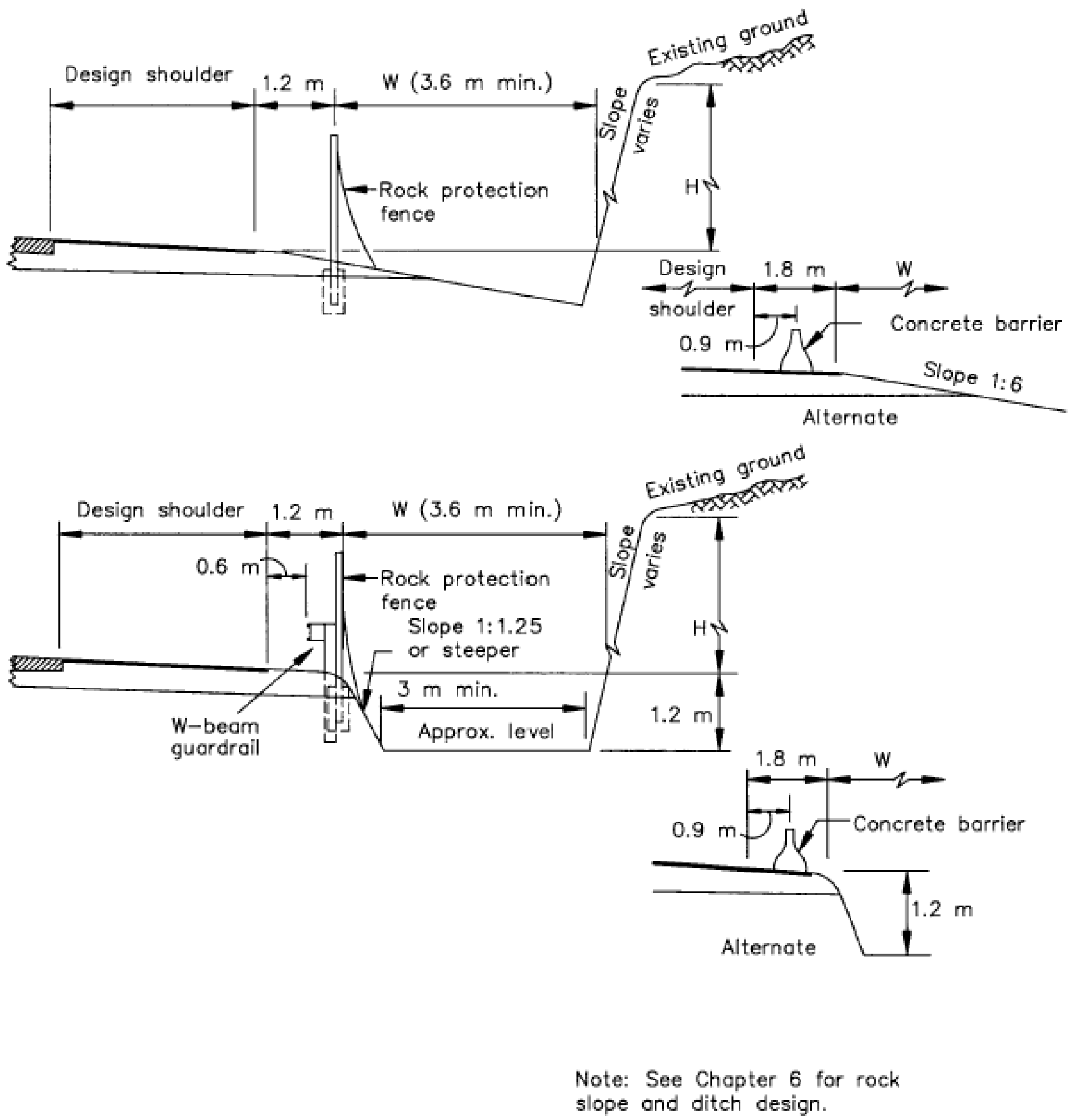
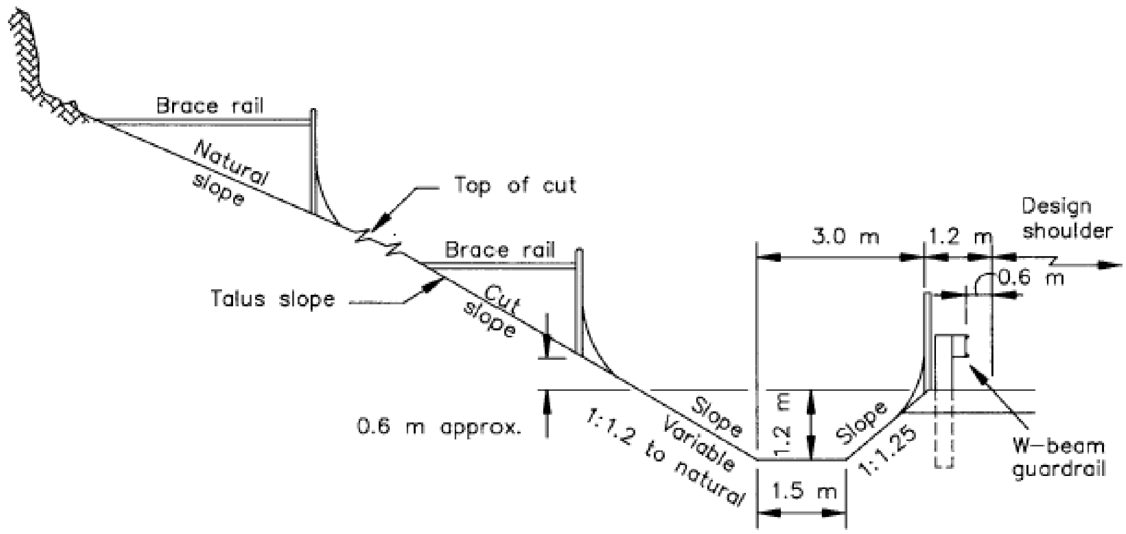
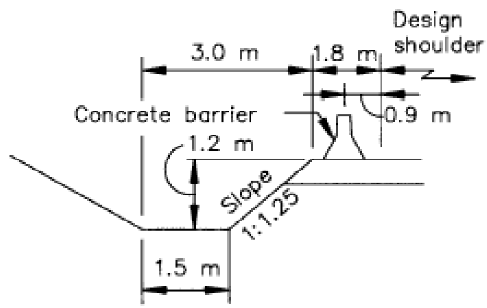


Exhibit 9.4-J FALLING ROCK CONTROL



Notes: Design fence for installation within a zone of 30 meters to 60 meters maximum from base of cliff (slope measurement).

Rock protection fence may be used in conjunction with concrete barrier alternate depending on site conditions.



Alternate

Exhibit 9.4-K ROLLING ROCK CONTROL

9.4.1.7.8 Serrated Slopes

Serrated slopes are a series of small steps in soft rippable rock cuts having slope ratios between 1.3V:1H and 1V:2H. The steps allow weathering and decomposing rock to accumulate to provide a growing medium for plants. The flat steps also retain moisture for use by the growing plants. When using serrated slopes, consider local environmental conditions, soil and plant growth potential. Exhibit 9.4-L shows a typical section of a serrated slope.

Include a drawing in the plans showing step tread and rise dimensions. Generally, the step rise varies from 0.5 m (1.7 ft) for easily ripped rock to 1.5 m (5.0 ft) for harder rippable rock. The step tread width is equal to the rise multiplied by the cut slope ratio.

9.4.1.7.9 Slope Rounding and Clearing Limits

Rounding at the top of cut slopes is especially important to reduce erosion and ensure long-term stability and revegetation of cut slopes. It also adds to the aesthetics of the finished project by blending the slope into the natural terrain. The amount of rounding may depend on the environmental impact and on the desires of the agency having jurisdiction.

It is FLHO policy to encourage the use of slope rounding on all projects.

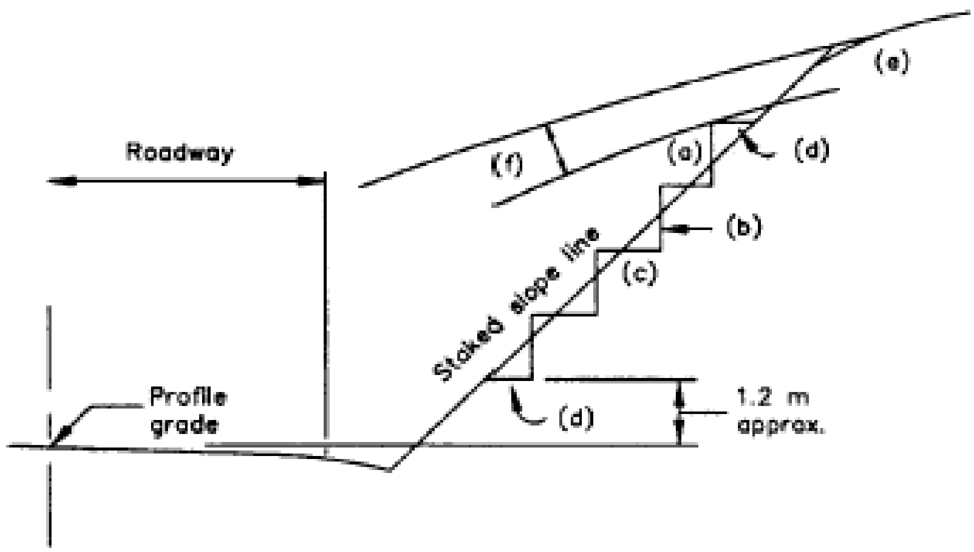
For low fills, it is desirable to have a clearing width beyond the edge of the travel lane that provides a clear zone for vehicles that may run off the road. This applies to daylighted sections and low cuts except in guardrail locations. Refer to the *Roadside Design Guide* for information on determining clear zone widths.

In some cases, the horizontal sight distance near intersections and on the insides of horizontal curves requires wider clearing than normal. Exhibits 9.4-F and Exhibit 9.4-H will aid in determining widening needed to provide adequate sight distance. When wider clearing is necessary, it shall show on the plans.

There are special cases where it is desirable to widen the clearing to create openings and irregularities in a long straight clearing line. The treatment will depend on the type, size and density of the trees and ground cover and on the terrain. Each case merits consideration on an individual basis.

9.4.1.8 Miscellaneous Roadway Widening

Roadways often require special consideration for additional widening for curves, auxiliary lanes, turnouts, etc.



Notes:
(a) 1:0.75 maximum slope.
(b) Step rise variable from 0.5 to 1.5 meters.
(c) Step tread = (a)(b)
(d) Ending step width = 0.5 (c).
(e) Normal slope rounding.
(f) Overburden area–variable slope ratio.

Exhibit 9.4-L SERRATED SLOPES

9.4.1.8.1 Curve Widening

The rear wheels of longer vehicles do not follow or track the front wheels on horizontal curves. To accommodate this, it is good practice to increase traveled way widths on curves, particularly when lane widths are less than 3.6 m (12 ft). Refer to the *Green Book* in Chapter 3, *Horizontal Alignment-Traveled Way Widening on Horizontal Curves*.

Traveled way widening values are shown in Exhibits 3-47 and 3-48 in the *Green Book*. For simple curves, place the widening on the inside of curves and transition it throughout the length of the superelevation runoff. The pavement joint and final centerline striping should split the pavement to provide equal widening to both lanes. For curves with spiral transitions, split the widening equally to both lanes and transition it on the spirals.

9.4.1.8.2 Auxiliary Lanes

Auxiliary lanes adjoin the traveled way and provide for parking, speed change, turning, weaving, truck climbing, passing or other purposes supplementary to through-traffic movement. They also maintain lane balance and accommodate entering and exiting traffic.

1. **Parking Lanes**. The design of arterial or expressway facilities should only permit emergency stopping or parking. Within most urban areas existing and developing land uses require on-street parking. This may also be true of small rural communities located on arterial highway routes.

   When land use development requires parking lanes, consider only parallel parking. Do not use diagonal or angle parking without a careful analysis of operational characteristics of the facility.

   The width of parking lanes can vary from 2.1 m to 3.6 m (7 ft to 12 ft) depending on the use of the lane for purposes other than parking automobiles. Refer to the *Green Book*, in Chapter 4 under *On-Street Parking*, in Chapter 5 under *Local Urban Streets-General Design Considerations*, in Chapter 6 under *Urban Collectors-General Design Considerations*, and in Chapter 7 under *Rural Arterials-Operational Control and Regulations* for criteria on design of parking lanes.

2. **Speed Change Lanes**. Vehicles use acceleration and deceleration lanes, including tapered areas, when entering or leaving the through traffic lanes. There are no definite warrants for providing speed change lanes. The *Green Book* provides guidance on the use of these lanes in Chapter 9, *Speed-Change Lanes at Intersections* and Chapter 10, *Ramps-Ramp Terminals*.

3. **Turning Lanes**. The designer will find criteria for left-turn lanes in the *Green Book*, Exhibit 9-75, and in Chapter 9 under *General Intersection Types-General Design Considerations*, *Speed-Change Lanes at Intersections*, and *Auxiliary Lanes*. For right-turn lanes refer to the *Green Book*, Chapter 9 under *Free-Flow Turning Roadways at*

Intersections and Exhibit 9-43. For deceleration lengths refer to Exhibits 10-71 and 10-73 in the *Green Book*.

4. **Weaving Sections**. The *Green Book* covers weaving sections in Chapter 2 under *Highway Capacity-Factors Other than Traffic Volume That Affect Operating Conditions* and *Design Service Flow Rates*, in Chapter 10 under *Interchanges-Four-Leg Designs-Cloverleafs* and under *Ramps-Ramp Terminals*

5. **Climbing Lanes**. Normally, climbing lanes are synonymous with truck traffic and steep grades. They should also be considered in recreational or other areas subject to slow-moving traffic.

   Steep downgrades have a negative effect on capacity and safety when used on facilities with high traffic volumes and numerous trucks.

   There are instances when providing a truck lane for slow moving downhill traffic (e.g., trucks, vehicles with trailers, recreational vehicles) is appropriate. Design climbing lanes independently for each direction of travel. Consider climbing lanes on two-lane highways under the following circumstances:

   - The upgrade traffic volume exceeds 200 VPH.
   - The upgrade truck volume exceeds 20 VPH.
   - The level of service E or F exists on the grade.
   - A reduction of two or more levels of service occurs when moving from the approach segment to the grade.
   - Trucks will experience a speed reduction of 15 km/h (10 mph) or greater.

   For anyone unfamiliar with the level of service concept, it is difficult to visualize the operating conditions that characterize levels of service A through F. Exhibit 2-31 of the *Green Book* presents a brief description of the operating characteristics for each level of service and type of highway.

   Refer to the *Green Book* in Chapter 3, *Vertical Alignment-Climbing Lanes* for details on designing climbing lanes on two-lane highways. The *Highway Capacity Manual* also contains sample calculations.

   For justification and design criteria for climbing lanes on multilane highways, read Chapter Three in the *Highway Capacity Manual* and the text in the *Green Book* in Chapter 3, *Vertical Alignment-Climbing Lanes-Climbing Lanes on Freeways and Multilane Highways*.

6. **Passing Lanes**. Refer to the *Green Book* in Chapter 3, *Vertical Alignment-Methods for Increasing Passing Opportunities on Two-Lane Roads* and the *Highway Capacity Manual* for information on the design of passing lanes.

9.4.1.8.3 Slow Moving Vehicle Turnouts

Technically these turnouts are not auxiliary lanes. They do provide room for a slow moving vehicle to pull safely off the roadway, then re-enter the through lane after faster moving vehicles pass.

Generally, the need for a turnout occurs on paved roadways for the following situations:

- with limited passing opportunities,
- when slow-moving vehicles are prominent but do not warrant climbing lanes, and
- where the cost of an auxiliary lane is prohibitive.

Exhibit 9.4-M provides guidance for width and length of turnouts. The riding surface of a turnout should be similar to the adjacent travel way. Provide adequate sight distance so the vehicle can re-enter the traffic stream safely. Sign all turnouts to identify their presence and purpose.

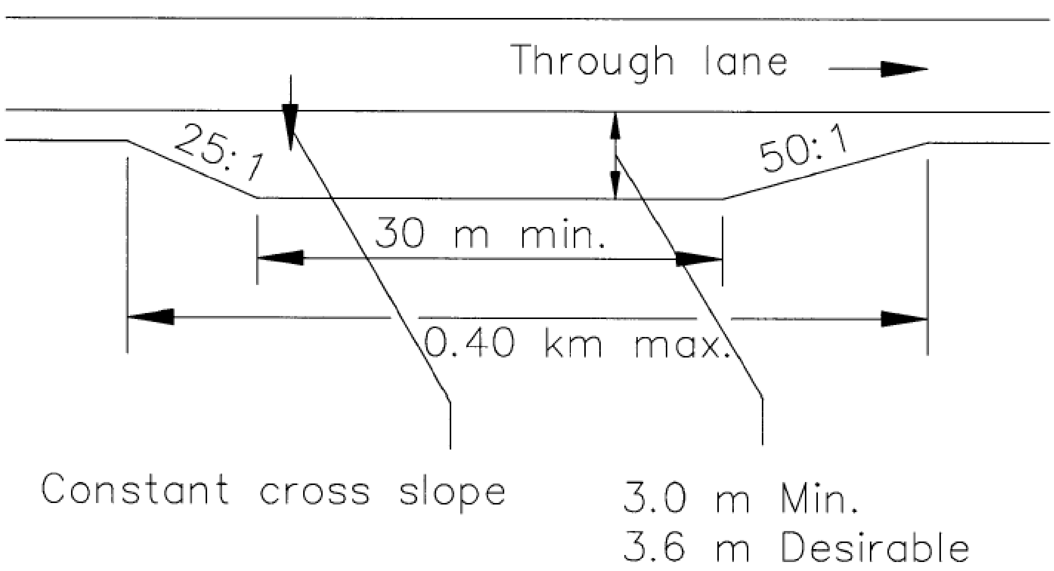


Exhibit 9.4-M SLOW MOVING VEHICLE TURNOUT

9.4.1.9 RRR Considerations

RRR projects primarily involve work on an existing roadway surface and/or subsurface. Their purpose is to extend the service life, provide additional pavement strength, restore or improve the original cross section, improve the ride of the roadway and enhance safety. An RRR project should not decrease the existing geometrics of the roadway section. See *FHWA Technical Advisory 5040.28* and TRB Special Report 214, *Designing Safer Roads* for additional information.

Funding restrictions may prevent the improvement of existing highways to the desirable standards. Therefore, when the pavement condition reaches minimal service level, there is a need for cost effective pavement and improvement projects.

RRR projects reflect and emphasize the economic management of the highway system. Therefore, economic considerations will largely determine the scope of work.

The following are some examples of factors that may influence the scope of a RRR project:

- roadside conditions,
- funding constraints,
- environmental concerns,
- changing traffic and land use patterns,
- pavement condition,
- traffic data, and
- crash data.

Acquisition of additional right-of-way to construct RRR improvements is sometimes necessary. Horizontal and vertical alignment modifications, if any, should be minor.

The designer should use a safety conscious design process (TA 5040.28) for RRR improvements. The designer should review the project in the field and include those items that will be practical enhancements to the project. These items may include the following:

- roadside obstacle removal,
- drainage improvements,
- slope rounding or flattening,
- traffic barrier,
- traffic control devices,
- shoulder improvements,
- minor widening,
- bridge rails and transitions,
- intersection improvements,
- railroad-crossing improvements, and
- illumination.

Many of these work items will enhance the project by providing the broadest scope of improvement possibilities.

Carefully establish project limits, particularly where widening occurs. Avoid ending the project at potentially hazardous locations (e.g., a narrow structure, a severe vertical or horizontal curvature). Provide the appropriate safety measures where these conditions are unavoidable.

All safety elements of an RRR project merit specific consideration. Collect and analyze crash numbers, types and rates for the project to identify safety problem areas. In addition, field reviews can identify potentially hazardous conditions.

While an analysis may indicate deficiencies in one or more of the following areas, each needs examination:

- horizontal and vertical alignment,
- cross-sectional geometrics,
- traffic control and positive guidance,
- access,
- railroad crossings,
- pedestrian/bicycle facilities,
- bridges and railings,
- illumination,
- signing and marking,
- channelization and delineation, and
- skid-resistant surface texture.

Improvements to the roadway surface may result in increased operating speeds. To maintain an acceptable level of operational safety, examine the geometrics and roadside conditions and modify them, if necessary.

Horizontal and vertical curvature and stopping sight distance directly relate to the speed of vehicles. As a consequence, deviations from the standards applicable to the current design speed of vehicles may cause safety problems.

When curvature is the cause of crashes, consider some corrective action. This can range from positive guidance (e.g., placement of additional warning signs and markings) to reconstruction. Often, existing horizontal and vertical alignments do not warrant reconstruction, and an analysis will show that they only require signing and marking, or other cost beneficial safety enhancements.

Consider alignment improvements when crash experience is high and previously installed warning signs, markings or other devices have been ineffective.

When the operating speed for a horizontal or vertical curve is less than 20 km/h (15 mph) below the operating speed of the adjacent sections, and has a low crash history, signs and marking may be applicable instead of reconstruction. When the difference is 20 km/h (15 mph) or more or the operating speed of the horizontal or vertical curve is less than 30 km/h (20 mph), corrective action is essential. If improvement to correct the difference in operating speed is not possible, provide the appropriate signs and markings and other provisions to best facilitate proper speed transition.

Sight distance improvement on horizontal curves and at intersections consists of flattening cut slopes, selective clearing or both. On completion of this work, measure the actual sight distance, determine the maximum comfortable speed and sign and mark the location.

As a rule, grades cannot be flattened significantly on RRR projects. However, steep grades and a combination of restricted horizontal or vertical curvature may warrant corrective action.

It is desirable to provide a roadside recovery area as wide as practical using the guidelines in the *Roadside Design Guide*. Evaluate the consistency of the clear zone throughout the project limits. Then determine the severity of each situation. Give particular attention to the clear zone at identified high roadside crash locations (fixed object crashes). Perform a cost and benefit analysis of appropriate measures (e.g., do nothing, remove, protect) to mitigate the hazardous conditions. On the basis of these analyses, select the appropriate remedial action. Pay special attention at the end of a downgrade for adequate clear zone on horizontal curves.

Consider widening to provide additional clear distance through short sections of rock cuts. In longer rock cuts, protrusions should be cut back or protected where warranted. A review of crash data will help to define dangerous obstructions. Good engineering judgment, cost effectiveness, analysis of operational and safety effects and consideration of environmental and community impacts may also influence decisions.

Under urban conditions, the minimum setback for obstructions should be outside the paved shoulder or 600 mm (2 ft) behind the curb. Where there will be sidewalks, it is desirable to locate the obstructions behind the sidewalk.

Safety items reduce the severity of run-off-the-road crashes. These items include traffic barriers (including bridge rails), barrier and bridge rail transitions, flattening slopes to eliminate the need for barriers, crash cushions, breakaway or yielding sign supports and breakaway luminaire supports.

All RRR projects should consider the following safety enhancements:

- Upgrading all rail and end treatments to current standards. Evaluate existing traffic barrier rail and transitions, bridge rail and transitions and guardrail and end treatments for need and compliance with standards.
- Extend cross pipes outside of the clear zone, if practical.
- Removing headwalls or non-traversable end sections within the clear zone and replacing with traversable end sections.
- Relocating, protecting or providing breakaway features for sign supports and luminaries.

- Shielding exposed bridge piers and abutments.
- Modifying raised drop inlets that present a hazard in the clear zone.
- Sign and mark all RRR projects according to the *MUTCD*.

9.4.2 Intersection Design

This section sets the basic guidelines to use in the design of at-grade intersections. The designer should also be familiar with Chapter Nine of the *Green Book*. For information on intersections with grade separation and interchanges, see Chapter Ten of the *Green Book*.

Intersections at-grade are a critical part of highway design. The efficiency of a road network depends on the effectiveness of the intersections. The number of possible conflicts at intersections is very high compared to normal roadway operations. Good design practice will minimize these areas of high crash potential. Traffic, driver characteristics, physical features, and economics influence the design of channelization and traffic control measures.

It would be ideal to design every intersection based on an engineering analysis using traffic data and crash records, but this is seldom practical. When an engineering study is appropriate, it should include recommendations for channelization, turn lanes, acceleration and deceleration lanes, intersection configuration and traffic control devices.

The speed at which vehicles approach and move through the intersection and the size of the design vehicle govern the minimum dimensions of an effective intersection. Such features as minimum sight distance, cure radii and lengths of turning and storage lanes directly relate to speed and design vehicle (see Section 9.4.2.2).

9.4.2.1 Intersection Types

The three-leg, four-leg and multi-leg configurations are the three basic types of intersections. (See the *Green Book* Exhibits 9-3 through 9-14) The following applies:

1. **Three-Leg Intersection**. The three-leg configuration is generally referred to as either a tee or Y intersection. The tee intersection has three legs intersecting so the angle between the stem of the tee and the remaining legs are 60 degrees to 120 degrees. It is desirable to keep this range between 75 degrees and 105 degrees with 90 degrees being the ideal. The tee shape provides better driver visibility than the Y shape. It is preferable to have the minor traffic movement on the stem of the tee.

   In the Y intersection, the angle between two of the intersecting legs is less than 60 degrees. The Y shape can cause driver confusion when two legs diverge from the stem and thus requires careful signing.

2. **Four-Leg Intersection**. The four-leg intersection is the most common type of intersection and may be right-angled, oblique or offset. The desirable angle between any two respective legs is between 75 degrees and 105 degrees, although the *Green Book* will allow a range from 60 degrees to 120 degrees with 90 degrees preferred.

   The right-angled crossing is easily signed and signalized, provides good visibility and is the safest to negotiate by drivers and pedestrians. The oblique crossing creates problems with driver visibility, pedestrian safety and vehicle turn angles. The offset intersection has low intersection capacity, is difficult to negotiate and comprehend, and is difficult to effectively sign and signalize. The through traffic movement on the major roadway should have the straight alignment.

3. **Multi-Leg Intersection**. The multi-leg intersection has more than four intersecting approach legs and can form several configurations. For purposes of this discussion, the rotary intersection is considered to be a multi-leg. These intersections have visibility problems and poor turning angles, confuse the road user, and are difficult to sign, mark and signalize. This type of intersection occurs when a highway diagonally cuts across a street grid system or when more than four approach legs intersect. The multi-leg configuration is not appropriate for new highways and the reconstruction of existing multi-legs to the four-leg type intersection is very desirable.

4. **Roundabout**. The "roundabout" intersection, a small radius version of a rotary intersection/traffic circle has worked well on some low-speed routes as replacements for intersections with two-way stops. It has been very successful in reducing crash severity; however site selection and proper design are critical to successful performance. See the *Green Book* Exhibits 9-15 through 9-17.

9.4.2.2 Design Vehicle

Design vehicles have selected dimensions and operating characteristics. Each represents a class of vehicles that establish design controls for specific conditions.

The design vehicle for any intersection depends on the roadways involved, the location of the intersection and the types and volume of vehicles using the intersection. Exhibit 9.4-N provides a guide to determine the design vehicle appropriate for various intersections.

Design an intersection so the design vehicle can make all turning movements without encroaching on adjacent lanes, opposing lanes, curbs or shoulders. Design the intersection with consideration that oversize vehicles, on necessary occasions, need to maneuver through the intersection with an allowable encroachment. Using a taper at the exit end of the right-turn corner will reduce the radius and the pavement area. For the recommended right-turn corner design, see Section 9.4.2.8.

9.4.2.3 Alignment

When the gradient of an intersecting roadway exceeds the cross slope of the through pavement, it is desirable to adjust the vertical alignment using suitable grades and vertical curves. Any adjustment should maintain sight distance.

In areas of ice or snow conditions it is desirable to use a three percent maximum grade, but the grade should not exceed five percent. A minimum grade of one-half percent (one percent desired) will provide for adequate drainage at an intersection.

When the desirable criteria are not attainable for an intersection, suitable curves introduced into the horizontal alignment of the less important road will reduce the angle of the intersection. The *Green Book* Exhibit 9-18 shows some examples of intersection horizontal realignments.

Often the cross slope of a road is in the same direction as the intersecting cross road. In this case adjust the vertical alignment of the cross road to meet the pavement cross slope of the highway.

If possible, avoid or eliminate intersections where the cross slope of the curving road is not in the same direction as the grade of the intersecting cross road. If this is unavoidable, adjust the vertical alignment of the cross road far enough from the intersection to obtain a desirable alignment.

9.4.2.4 Sight Distance

The operator of a vehicle approaching an at-grade intersection needs an unobstructed view of the entire intersection and sufficient length of the intersecting roadway. Refer to the Green Book in Chapter 9, *Intersection Sight Distance*. Under some conditions, when it is impractical to provide adequate site distance for cross road traffic to safely enter the main road, it may be necessary to install traffic signals. (See Part Four of the *MUTCD*.)

Many intersections use stop signs on the minor road for traffic control. In this case, the driver stopped on the minor road must see enough of the major highway to safely cross before a vehicle on the major highway can reach the intersection.

Refer to the *Green Book*, Exhibit 9-55 for minimum sight distance along the major road for level conditions, for left turn from stop. Refer to the *Green Book*, Exhibit 9-53 for adjustment of sight distance to reflect grades of the minor road approach.

Within the sight triangle, remove, adjust or lower cut slopes, hedges, trees, signs, utility poles or anything large enough to constitute a sight obstruction (see the *Green Book*, Exhibit 9-50). Eliminate parking and offset signs to prevent sight distance obstructions.

Metric				
Intersection Type	**Design Vehicles**		**Radius (m)**	
	Des.	Min.	Des.	Min.
Junction of Major Truck Routes	WB-19	WB-19	35	30
Junction of State Routes	WB-15	WB-12	30	23
Ramp Terminals	WB-15	WB-12	30	23
Other Rural	WB-12	SU	23	17
Urban Industrial	WB-12	SU	23	17
Urban Commercial	SU	P	17	11
Residential	SU	P	17	11
US Customary				
Intersection Type	**Design Vehicles**		**Radius (ft)**	
	Des.	Min.	Des.	Min.
Junction of Major Truck Routes	WB-62	WB-62	115	100
Junction of State Routes	WB-50	WB-40	100	75
Ramp Terminals	WB-50	WB-40	100	75
Other Rural	WB-40	SU	75	60
Urban Industrial	WB-40	SU	75	60
Urban Commercial	SU	P	60	40
Residential	SU	P	60	40

Note:

P = Passenger car, including light delivery trucks
SU = Single unit truck
WB-12 (WB-40) = Semitrailer truck, overall wheelbase of 12 m (40 ft)
WB-15 (WB-50) = Semitrailer truck, overall wheelbase of 15 m (50 ft)
WB-19 (WB-62) = Semitrailer truck, overall wheelbase of 19 m (65 ft)

Exhibit 9.4-N INTERSECTION DESIGN VEHICLE

The SU vehicle commonly serves as the design vehicle for most rural highway conditions, including most recreational roads. If there is significant semi-truck traffic, use the WB-15 (WB-50) or WB-19 (WB-62) vehicles. In areas where SU or WB vehicles are not prevalent, and right-of-way restrictions prohibit adequate sight triangle clearing, the P design vehicle may be applicable.

At some intersections, the turning volume from a stop-controlled minor roadway is significant enough to conflict with through vehicles on the major roadway. In these instances, intersection sight distances based on gap acceptance are recommended. For intersection sight distance in design of a left turn from stop based on gap acceptance refer to the *Green Book*, Exhibit 9-54 and Equation 9-1. The distances derived are the sight distances required for vehicles to turn left from stop onto a two-lane highway and attain an average running speed without being overtaken by a vehicle going the same direction. Using sight distances less than that required for the design vehicle will require the through traffic to reduce speed.

For additional information on sight distance and for sight distance across divided highways, refer to Chapter 9 of the *Green Book*.

9.4.2.5 Channelization

Channelization separates traffic into definite paths of travel using pavement markings or raised islands. Channelization facilitates the safe and orderly movement of vehicles, bicycles and pedestrians.

Pavement markings used to delineate travel paths generally consist of painted stripes reflectorized with glass beads. Raised Pavement Markers (RPM), reflectorized and nonreflectorized, may supplement pavement striping when increased visibility is desirable. RPM may replace painted stripes when climatic or traffic conditions warrant. (See Chapter Eight).

Curbing is permissible for channelization under the following conditions:

- prevention of mid-block left turns;
- raised divisional and directional islands;
- raised islands with luminaries, signals or other traffic control devices;
- pedestrian refuge islands; and
- landscaped areas within the roadway.

Curbing is undesirable at any location where painted pavement markings with or without reflective lane markers attain the same objective.

Try to limit the use of curbing to urban and suburban highways with a design speed of 60 km/h (40 mph) or less. On these types of highways, drivers expect to encounter confined facilities and raised channelization works well.

The two general classifications of curbing for channelization are sloping curbs and vertical curbs of the types shown in Exhibit 4-6 of the *Green Book*. For safety considerations, use sloping curbing whenever possible. Use vertical curb for raised islands with luminaries or traffic control devices and for pedestrian refuge.

Exhibit 9.4-O shows the minimum offset distances recommended for vertical curb. For sloping curbing installations, the left offset distance is optional.

Lane Width	**Left**		**Right (Min.)**
	Rural	Urban	Rural and Urban
Metric			
3.6 m	0.3 m	0.3 m	1 m
3.3 m	0.6 m	0.3 m	1 m
3.0 m	1.0 m	0.6 m	1 m
US Customary			
12 ft	1 ft	1 ft	3 ft
11 ft	2 ft	1 ft	3 ft
10 ft	3 ft	2 ft	3 ft

Exhibit 9.4-O OFFSET DISTANCES FOR VERTICAL CURB

9.4.2.6 Traffic Islands

A traffic island is a defined area between traffic lanes for control of vehicle movements, pedestrian refuge or traffic control devices. The use of raised traffic islands should be limited to those urban and suburban highways with a design speed of 60 km/h (40 mph) or less.

Traffic islands perform these major functions:

- channelization islands control and direct traffic movement,
- divisional islands separate opposing or same direction traffic streams, and
- refuge islands provide for proper placement of traffic control devices.

Divisional and refuge islands are normally elongated and should be at least 1.2 m (4 ft) wide and 6 m (20 ft) long.

Channelization islands are typically triangular. In rural areas they should contain an area of at least 7 m^2 (75 ft^2) with 9 m^2 (100 ft^2) as a desirable minimum. In urban areas where speeds are low, islands about two-thirds this size may be acceptable. Islands with traffic control devices or luminaries and islands crossed by pedestrians require 18 m^2 (200 ft^2) as a minimum area.

Design triangular shaped islands as shown in the *Green Book* Exhibits 9-37 or 9-38 for urban or rural locations, respectively. For painted islands in rural areas, these offset distances are desirable but not mandatory.

Avoid offset distance wider than 1.5 m (5 ft) as this gives the appearance of an added lane. Reflective RPMs may supplement island markings.

Raised islands at crosswalk locations require barrier-free access for the handicapped. (See Section 9.4.2.6).

Design approach ends of islands to provide adequate visibility and advance warning of their presence. Islands should not cause a sudden change in vehicle direction or speed. Transverse lane shifts should begin far enough in advance of the intersection to allow gradual transitions. Avoid introducing islands on a horizontal or vertical curve. When islands on curves are unavoidable, adequate sight distance, illumination and/or the extension of the island must be considered.

See the *Green Book* in Chapter 9, *Islands* for additional design criteria for islands and Part Three of the *MUTCD* for markings for the islands.

9.4.2.7 Left-Turn Lanes

A left-turn lane is an auxiliary lane on the left side of a one-directional pavement for use as speed change and storage of left-turning vehicles. Left-turn movements result in more critical traffic conflicts than do right-turn movements. Design left-turn channelization with enough operational flexibility to function under peak loads and adverse conditions. Left-turn lanes are an economical way to reduce delays and crashes at intersections.

At unsignalized intersections on two-lane highways, use Exhibit 9.4-P for guidance on the need for left-turn lanes. Left-turn lanes are appropriate at locations where crashes involving left-turning vehicles are high. Refer to Exhibits 9.4-Q through 9.4-T to determine the storage length required. The minimum storage length should be 30 m (100 ft). At signalized intersections, the left-turn storage length is dependent on capacity and level-of-service criteria found in the *Highway Capacity Manual*.

Offsets and pavement widening should be symmetrical about centerline or baseline. Widen on one side only when right-of-way, topography, alignment restrictions or other circumstances prevent symmetrical widening. See the *Green Book* for additional design guides and for left-turn treatments on multilane facilities.

9.4.2.8 Right-Turn Lanes

Right-turn corner designs should allow the design vehicle to turn without encroaching on adjacent lanes, curbs, shoulder edges or opposing traffic lanes For a simple radius without the exit taper, the values in Exhibit 9.4-N apply; however, this will increase the pavement area. At signalized intersections, some encroachment on adjacent lanes of the approach leg is usually acceptable to obtain an adequate radius.

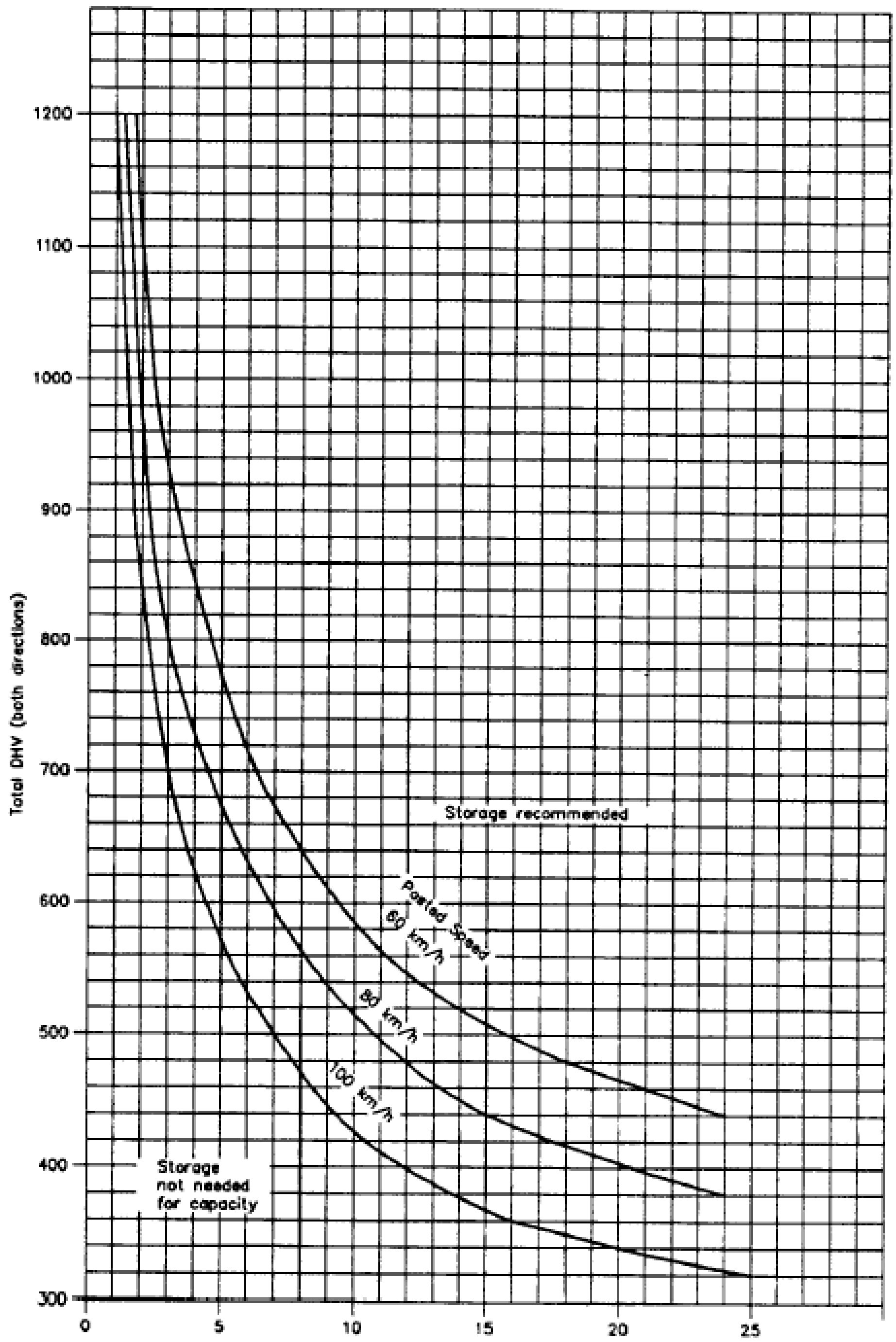


Exhibit 9.4-P LEFT-TURN STORAGE GUIDELINES FOR UNSIGNALIZED TWO-LANE HIGHWAY INTERSECTIONS
(Metric)

To Be Provided

Exhibit 9.4-P LEFT-TURN STORAGE GUIDELINES FOR UNSIGNALIZED TWO-LANE HIGHWAY INTERSECTIONS (US Customary)

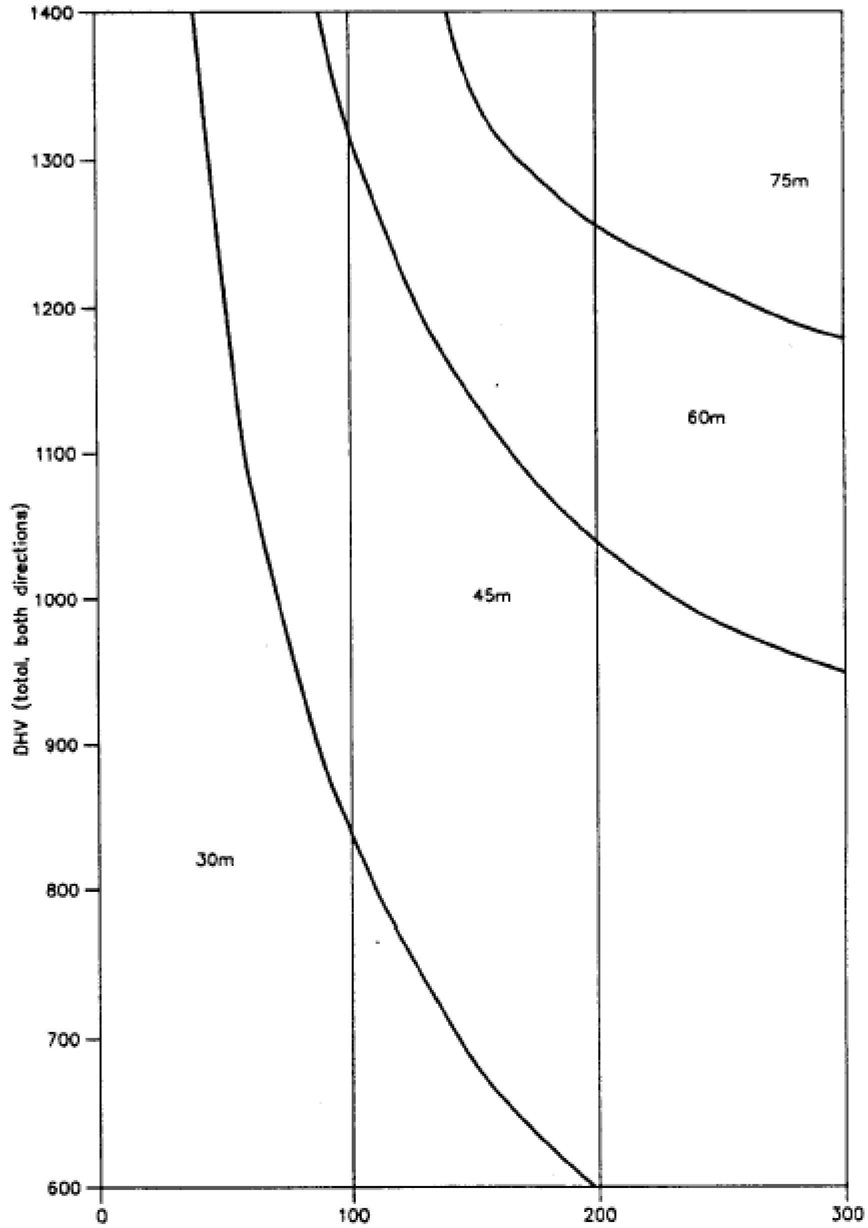


Exhibit 9.4-Q LEFT-TURN STORAGE LENGTHS FOR UNSIGNALIZED TWO-LANE HIGHWAY INTERSECTIONS
(60 km/h Posted Speed)
(Metric)

To Be Provided

Exhibit 9.4-Q LEFT-TURN STORAGE LENGTHS FOR UNSIGNALIZED TWO-LANE HIGHWAY INTERSECTIONS
(40 mph Posted Speed)
(US Customary)

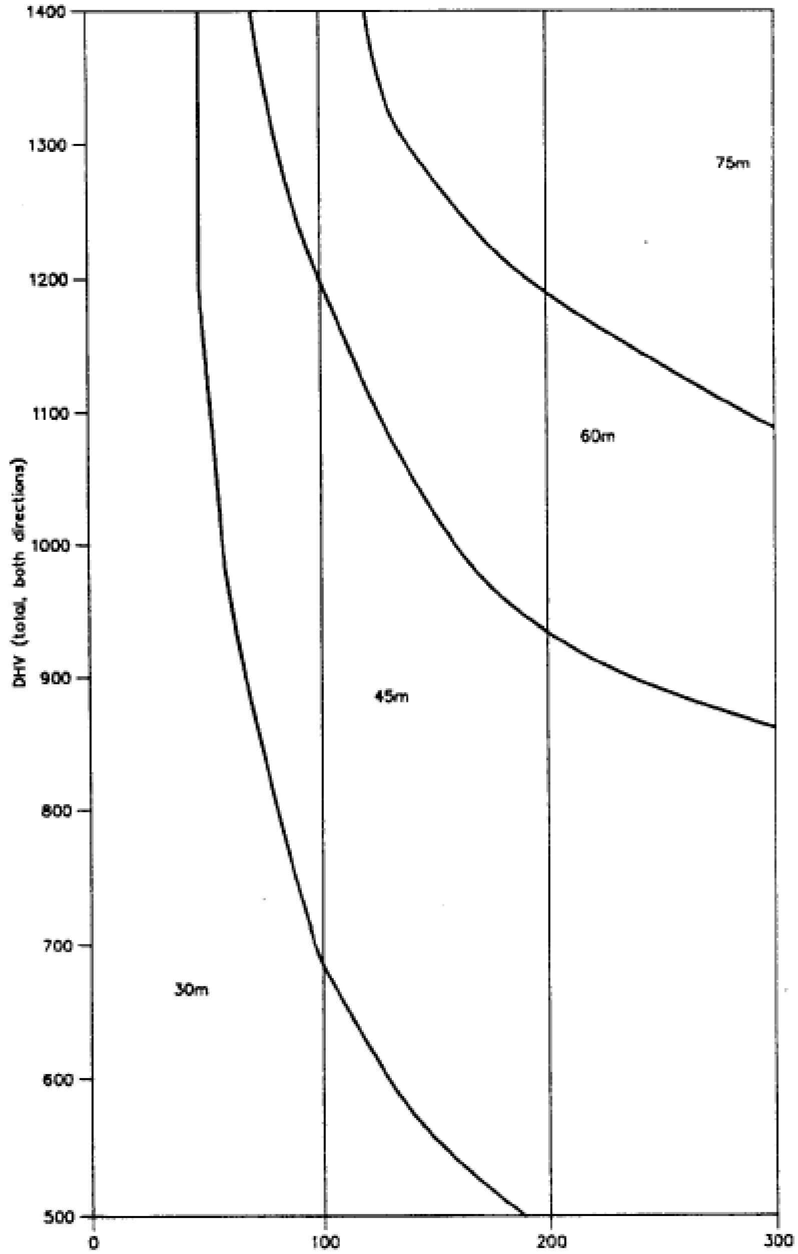


Exhibit 9.4-R LEFT-TURN STORAGE LENGTHS FOR UNSIGNALIZED TWO-LANE HIGHWAY INTERSECTIONS
(80 km/h Posted Speed)
(Metric)

To Be Provided

Exhibit 9.4-R LEFT-TURN STORAGE LENGTHS FOR UNSIGNALIZED TWO-LANE HIGHWAY INTERSECTIONS (50 mph Posted Speed) (US Customary)

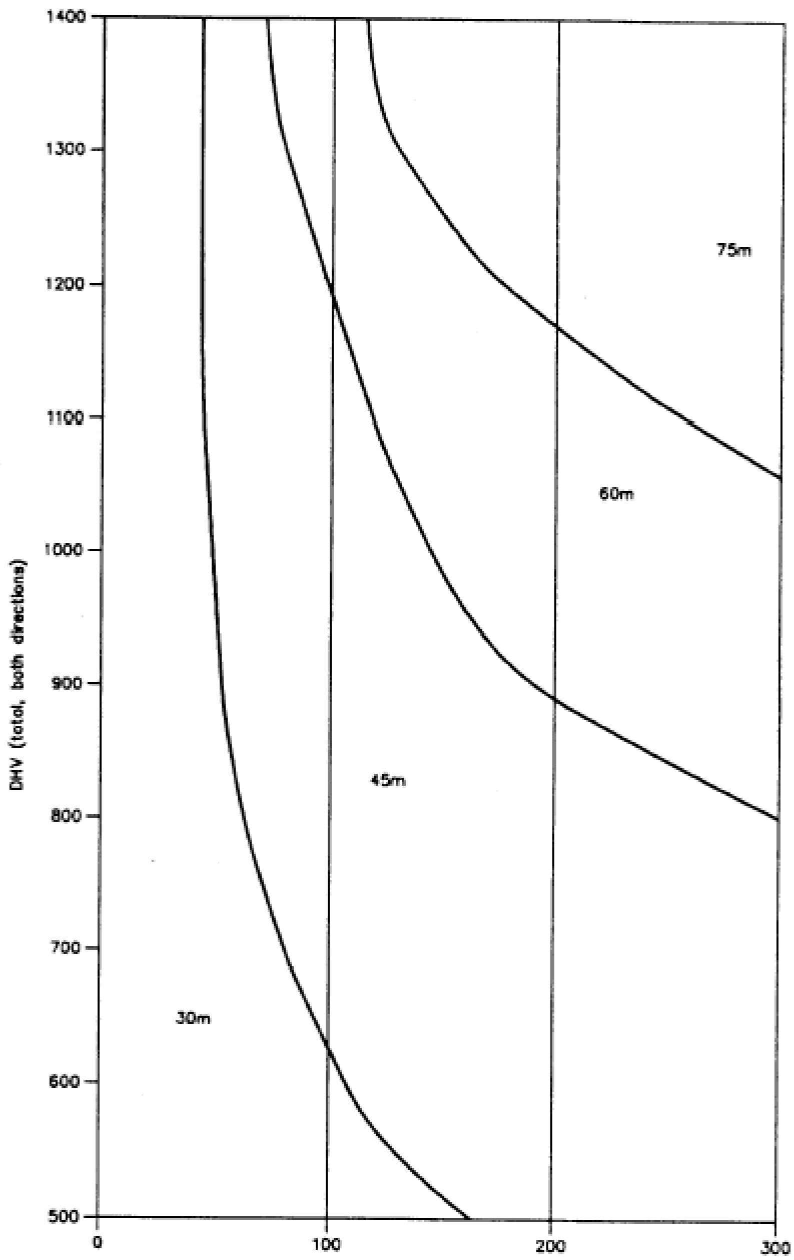


Exhibit 9.4-S LEFT-TURN STORAGE LENGTH FOR UNSIGNALIZED TWO-LANE HIGHWAY INTERSECTIONS (100 km/h Posted Speed) (Metric)

To Be Provided

Exhibit 9.4-S LEFT-TURN STORAGE LENGTH FOR UNSIGNALIZED TWO-LANE HIGHWAY INTERSECTIONS (60 mph Posted Speed) (US Customary)

Standard Storage Length	Trucks in Left-Turn Movement				
	10%	20%	30%	40%	50%
	Additional storage length to be added to standard values of left turn lengths.				
Metric					
30 m	7.5 m	7.5 m	15 m	15 m	15 m
45 m	7.5 m	15 m	15 m	22.5 m	22.5 m
60 m	7.5 m	15 m	22.5 m	30 m	30 m
US Customary					
100 ft	25 ft	25 ft	50 ft	50 ft	50 ft
150 ft	25 ft	50 ft	50 ft	75 ft	75 ft
200 ft	25 ft	50 ft	75 ft	100 ft	100 ft

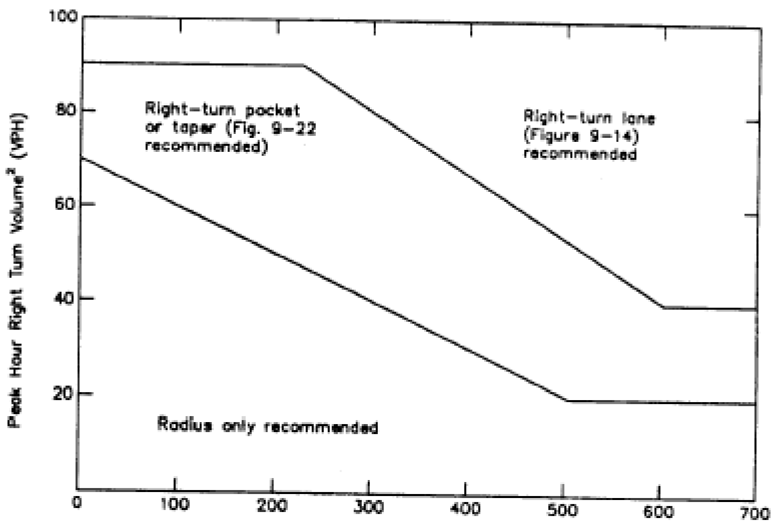
Exhibit 9.4-T ADDITIONAL LEFT-TURN STORAGE FOR TRUCKS AT UNSIGNALIZED TWO-LANE HIGHWAY INTERSECTIONS

Compound curves may reduce the need for additional pavement area. See the *Green Book* for a discussion of compound curves and other guidelines for corner radius returns.

Right-turn movements at intersections influence intersection capacity, although not usually to the same extent as left-turning movements. Conflicts between the opposing traffic and the right-turning vehicle is not a factor. Right-turning vehicles are affected by pedestrian movements, especially those in the crosswalk of the leg into which the turn is being made.

Consider right-turn lanes at unsignalized intersections when:

- approach and right-turn traffic volumes are high (See Exhibit 9.4-U),
- presence of pedestrians requires right-turning vehicles to stop in the through lanes,
- Restrictive geometrics require right-turning vehicles to slow considerably below the speed of the through traffic.



Peak Hour Approach Volume[1] (VPH)

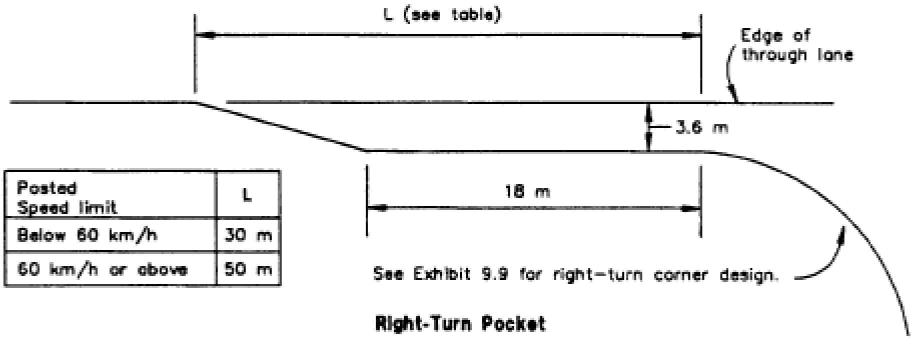
Notes:

1. *For two-lane highways use the total peak hour approach volume. For multi-lane, high Speed (posted at 70 km/h (45 mph) or above) highways use the total peak hour approach volume per lane.*

2. *Reduce peak hour right\-turn volume by 20 VPH when all three of the following conditions are met.*

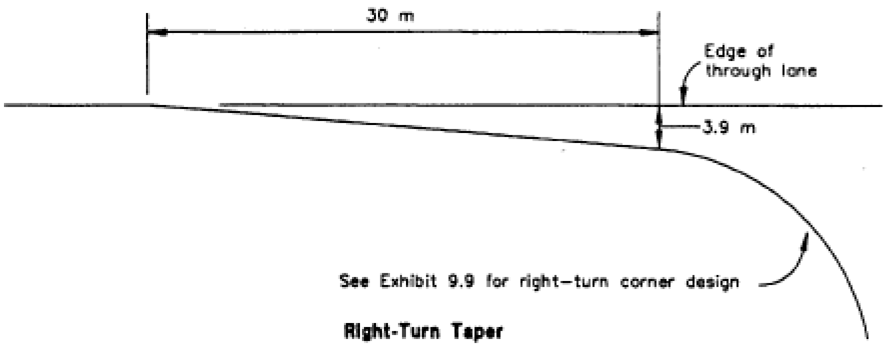
   Posted speed $\leq$ 70 km/h (45 mph)
   Right-turn volume $>$ 40 VPH
   Total approach volume $<$ 300 VPH

Exhibit 9.4-U RIGHT-TURN LANE GUIDELINES



Posted Speed limit	L
Below 60 km/h	30 m
60 km/h or above	50 m

Right-Turn Pocket



Right-Turn Taper

Exhibit 9.4-V RIGHT-TURN POCKET OR TAPER

- The decision sight distance is below minimum at the approach to the intersection.
- Crashes involving right-turning vehicles are high.

At signalized intersections, a capacity analysis using the *Highway Capacity Manual* will determine if right-turn lanes are necessary to maintain the desired level of service.

Where adequate right-of-way exists, providing right-turn lanes is cost-effective and can provide increased safety and operational efficiency.